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ABSTRACT

This program identified applications and developed design characteristics for generalized training devices. The first of three sequential phases reviewed in detail new developments in Naval equipment technology that influence the design of maintenance training devices: solid-state circuitry, modularization, digital technology, standardization, functional packaging, general-purpose displays, computer aiding, automatic test equipment, lifetime spares design, life-cycle costing, and total system design. In the second phase, three generalized training devices were recommended for development: 1) a digital systems training device, 2) a communications system training device, and 3) a generalized torpedo maintenance training device. In the third phase, the design and use characteristics of each of the three devices were developed, with emphasis on the digital systems device. Each of them was developed to the functional block diagram level. On the basis of these studies, recommendations are made for the inclusion of computer-assisted instruction techniques as they relate to the digital systems trainer. (Author/JK)

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APPLICATION AND DESIGN CHARACTERISTICS OF GENERALIZED TRAINING DEVICES

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ABSTRACT

The purpose of this study program was to identify applications and develop design characteristics for generalized training devices. A secondary, but important, objective of the study was to forecast the impact on generalized training devices of new developments and design trends for Naval electronic equipment, maintenance procedures, and new training techniques.

The study was conducted in three sequential phases. The first phase was a detailed review of new developments in Naval equipment technology that influence the design of maintenance training devices--solid-state circuitry, modularization, digital technology, standardization, functional packaging, general-purpose displays, computer aiding, automatic test equipment, lifetime spares design, life-cycle costing, and total system design. Each of these developments is reviewed and its impact explained. Then, a series of long-term design trends is described and related to training device requirements of the future.

The second phase of the study had two general objectives: (1) to examine present training practices in electronics maintenance for a series of selected Naval rates, and (2) to identify skill and knowledge requirements created by Naval systems now in the conceptual and engineering design stages of their development cycles. As a result, three generalized training devices were recommended for development: (1) a digital systems training device, (2) a communications system training device, and (3) a generalized torpedo maintenance training device.

The objective of the third phase of the study was to develop the design and use characteristics of the three recommended training devices with particular emphasis on the Digital Systems Trainer. Each of the three devices is developed to the functional block diagram level and its role in Naval training is described, including the school(s) for which it was intended.

Finally, recommendations are made for the inclusion of computer-assisted instruction techniques as they relate to the digital systems trainer.

FOREWORD

This study differs from previous studies in the generalized trainer field in several important aspects. Previous studies were concerned with operational equipment currently in the Fleet and with the feasibility of within-family (sonar, fire-control) training devices. In this effort, new developments in equipment technology have been carefully examined and related to current and future training device requirements. These new developments, particularly the Standard Hardware Program, lead to ever increasing commonalities among equipments so that across-family training devices will be the rule and not the exception. It is also forecast that future operator trainers and maintenance trainers, while differing in training use, may have as much as eighty percent of their hardware in common. In addition, the increasing use of digital technology in equipments makes it readily possible to utilize computer-assisted instruction.

Three generalized training devices, for which an immediate need is seen, are described and their utilization in Naval training detailed.

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SECTION I

INTRODUCTION

During recent years, the validity of the generalized training device concept has been established firmly. Experience gained with these devices has shown them to be highly practical, both with respect to criteria of training efficiency and cost-effectiveness. These favorable results have led to the conclusion that it is now appropriate to systematically review the various families of Naval electronics systems and to establish, for each family, the applicability and desirability of the generalized training device approach.

The purpose of the research reported here was to identify areas of Naval electronic training that can potentially benefit from the development of generalized training devices, and to define the design and use characteristics of several such devices as appropriate. By direction, the primary emphasis of the study was on maintenance training, but the technical approach developed is also applicable to operator training. The single most promising generalized training device has been identified and its characteristics are developed herein in considerable detail.

Generalized training devices, like other electronic systems, require lengthy developmental cycles. It was considered critical, therefore, that the design of such devices be based on timely and accurate forecasts of training requirements that will prevail during the "use" period of their life-cycles. It was also considered critical to carefully examine new technological developments and to forecast future system characteristics in a way that would promote maximum effectiveness of future training devices. Therefore, new technological developments and system design trends were studied, and are described herein, that will importantly influence the design of future training devices, both generalized and system specific.

OVERVIEW OF THE STUDY

The study was conducted in three phases. Phase I, the "Survey and Data Collection" phase, had as the primary objective a detailed and accurate assessment of the direction which Naval electronics will take in future years. Phase II, the "Equipment Analysis" phase, had as the primary objective the identification of electronic-training areas which lend themselves to the development of generalized training devices, considering carefully the time required for developing such devices to the stage of operational use. Phase III, the "Detailed Design" phase, had as the primary objective the development of engineering characteristics and the expected use pattern of three recommended generalized maintenance training devices, the most promising of the three in considerable detail.

The study can best be characterized as a survey of existing equipment and new developments to identify present maintenance practices and to make a projection of future requirements on a time scale. Then, the information acquired was used to formulate the design and use characteristics of recommended generalized training devices, and finally was translated into the engineering characteristics and the expected use pattern of the single most promising trainer. Each of the three study phases consisted of several sub-tasks that are described in detail herein. One sub-task of primary importance was the assessment of the applicability of computer-assisted instructional techniques to generalized training devices for electronics maintenance.

The conclusions and recommendations contained in this report apply, in the main, to training device development in general, not just to the development of generalized devices. The technology of electronics has changed rather dramatically during the last few years, perhaps more than during any other period in history. Innovative techniques have been developed that vastly improve reliability and ease the burden of maintenance. Many of these technological advances already have been incorporated into Naval electronic systems. However, the unavoidable lag between the development and the application of new

techniques means that the newest advances are not yet represented in the Fleet, and the technology is presently advancing at a greater and greater rate. As a consequence, important and dramatic changes are projected in the tasks performed by electronic maintenance technicians and system operators. These changes, in turn, will have a profound effect on Naval electronics training and on training device design, both generalized and system-specific.

Project personnel felt that the philosophy underlying generalized training device studies had not been developed systematically elsewhere. Therefore, the next section of this report contains a lengthy development of the frame-of-reference pertaining to generalized training device development as seen by personnel of Anacapa Sciences.

SECTION II

THE PHILOSOPHY OF GENERALIZED TRAINING DEVICES

The existence of common task requirements is central to all generalized training device developments, based on the principle that skill and knowledge elements acquired using such devices will transfer to the parent electronic systems. If two or more electronic systems require common operator or common maintenance tasks, the possibility is opened that the tasks can be trained in the same classroom, trained using the same device, or both. Therefore, potential applications for generalized training devices result from task commonality for the operation or maintenance of electronic systems.

The purpose of this section of the report is to develop a philosophy for generalized training devices. This philosophy will provide a frame of reference within which to interpret the various dimensions of electronic change that are developed throughout the report.

COMMON TASK REQUIREMENTS FOR MAINTENANCE AND OPERATION

All electronic devices and systems, no matter how simple or complex, derive from a common set of physical/electronic principles. All electronic components, because of their physical properties, exert a predictable influence on the nature of electrical energy; the type of influence is determined by the unique physical characteristics of each component. These influences are called resistance, reactance, impedance, etc.; they are the forces that the electronic designer manipulates to cause the form of electrical signals to be changed. The nature of the change desired depends on the operational and functional objective to be served by the equipment block or section under design. These objectives, in turn, stem from the basic purpose or mission of the equipment. In effect, a series of constraints is placed on the equipment designer by the objectives of the system and its subsystems. Electronic designers, in response to

specific design requirements, tend to behave alike. Thus, to the extent that operational or functional requirements are similar, equipment features are likely to be similar.

Any two items of electronic equipment, even if selected at random, will exhibit some commonality of design features and some commonality of maintenance and operational requirements generated by these features. Common task requirements can exist among members of the same "family" of electronic systems--radars, communication sets, sonars, and navigation devices. Task commonality can also exist across families of electronic systems, whenever operational or maintenance features are similar. However, if two electronic systems are selected from the same family, all else held constant, the probability is higher that common maintenance or operator tasks will be required than if the systems are selected from different families.

If two electronic systems share the same maintenance philosophy (planned techniques of replacement/repair) or if their physical and constructional features are similar, it is likely that common tasks will be required. It is also likely that two systems designed during the same time period will be based on similar maintenance philosophies and thus will have similar physical and constructional characteristics. Equipment from different generations, though their operational features could be identical, can require completely different maintenance tasks.

An important point, to be developed more fully later in the report, is that task commonality created by constructional similarity is greater than that contributed by functional similarity. A sonar and a radar that are physically similar by nature of having the same maintenance philosophy (for example, modularized construction with throw-away modules) will share more common task requirements than will two radars that are functionally identical but physically dissimilar. In short, commonality of maintenance tasks is directly and importantly determined by the maintenance philosophy that guided the system design and by the constructional techniques used to implement the design.

The importance of constructional similarity, particularly within a rapidly changing technology, establishes the requirement to forecast system design trends, essentially to establish the maintenance and repair philosophy planned for future equipment. If this is not done, designs of generalized maintenance training devices might be based, as they have been in the past, largely on functional similarity, a practice valid only in a period of unchanging technology.

TIMING OF GENERALIZED TRAINING DEVICE DESIGN

In the past, generalized training device designs were based on the identification of common tasks required by representative samples of existing equipments within a family. For example, a group of sonar systems was examined to identify the common maintenance task elements required by these systems. The common features were later incorporated into a generalized trainer. This work was done at a point in time when all sonar systems were analog devices and all constructional techniques employed in building sonar sets were fairly standard. Since that time, design and construction has begun on an entirely new family of sonar systems for submarines and destroyers. These new systems not only are primarily digital, but are based on a completely different maintenance philosophy (substitution of defective throw-away modules discovered using automatic fault-location equipment). As a result, there is little commonality between maintenance tasks of existing sonars and those required by new sonars now on the drawing board. Such major change is typical of many areas of Naval electronics.

Electronic systems presently installed aboard ship and in Naval shore installations are being retrofitted almost constantly to improve their performance. The portions of the system being replaced usually are designed using items of the new technology; they are almost always digital. Many electronic systems are being provided with analog-to-digital conversion equipment to allow the systems to communicate with shipboard computer equipment. Because of the swing to new technologies, the traditional technique of identifying common tasks required by existing equipments

within a family would appear valid only when it can be established that no important changes will occur in the equipment family in the future.

There are, of course, families of Naval electronic equipment that do not lend themselves readily to the swing to digital technology or any of the new maintenance concepts. One such area is Super-High-Frequency (SHF) communications. SHF systems contain mostly electromechanical components (klystrons, magnetrons, waveguides, and directional couplers), whose mechanical shape and structure are fixed by the nature of the energy that they conduct. It can safely be predicted that devices of this type will not be part of the general swing to digital implementation.

It is considered vital that future designs of generalized training devices are based on the identification of common maintenance tasks required by systems under development and planned for the future. As will be discussed in Section V of this report, the changeover to digital technology will reduce the number of divergent maintenance tasks required by Naval electronic equipment, although the complexity of some of these tasks may exceed that which exists at the present time.

PROJECTION OF SKILL AND KNOWLEDGE REQUIREMENTS

Requirements for maintenance of electronic systems most often are identified and developed using task analysis procedures (sometimes called maintenance requirements analyses or maintenance engineering analyses). A task analysis for maintenance is a detailed description of the hierarchy of tasks and subtasks required to complete a specified maintenance routine. Such analyses are fairly straightforward and simple to perform once the equipment becomes available and some experience has accumulated in maintaining the system.

Task analyses sometimes are attempted for equipment undergoing development. For equipment in the planning stage, however, skill and knowledge requirements must be inferred from the physical, functional, and constructional features of the equipment and from the maintenance and repair philosophy adopted by the designer. For example, if the maintenance philosophy includes the use of throw-away modules, it can be

predicted accurately that troubleshooting and repair to the individual component level will not be required as it is with today's equipment. It can also be predicted accurately that the maintenance technician will have to operate automatic test equipment or administer prescribed fault-localization routines to isolate the faulty module, remove modules suspected of malfunctions, substitute good modules for bad, and perform tests to ensure that the equipment has been restored to proper operation. It is less important to conduct detailed task analyses of maintenance actions for new electronic systems because of their almost universal adherence to modular design, digital implementation, and automatic fault location. Since the physical similarity among systems now being designed is increasing, the commonality of maintenance actions required is also increasing. The effect also increases the expected transfer of skill and knowledge elements from one electronic system to another.

If constructional similarity is recognized as being a more important determiner of maintenance task commonality than functional similarity, it is easy to see that the trend toward modularization increases task commonality both within and across families of electronic systems. As stated, a radar set and a sonar set with similar philosophies of replacement and repair will share many more maintenance task requirements than will two radar sets or two sonar sets that are functional equivalents but that differ in repair and replacement philosophy.

COST EFFECTIVENESS OF GENERALIZED TRAINING DEVICES

It is important to distinguish between the feasibility and the desirability of developing a generalized training device. Development is feasible whenever commonality of task requirements can be established. There may be a question of whether the extent of such commonality is sufficiently high to justify the cost of such a device, but it is feasible.

The desirability (essentially the training-cost-effectiveness) of developing a generalized training device is determined by several factors: (1) the total number of units of the parent system planned for production, (2) the total cost of each parent system, (3) the size and complexity of

the parent system, (4) the maintenance philosophy of the parent system, and (5) the existing training situation.

The total number of units of the parent system to be produced is critically important because it directly determines the overall required manning level and thus the number of maintenance technicians to be trained. This factor, in turn, determines the potential level of utilization of the trainer. There are, for example, several command and control systems currently being designed for installation aboard ship. These are highly complex electronic systems that create a formidable maintenance load for the technicians assigned. However, there are only a handful of such systems planned for production, perhaps on the order of four to six. Since the theoretical complement of maintenance technicians required is approximately 36, it would not be cost-effective to design and build a generalized trainer.

The cost of the parent system is perhaps the single most important factor determining the desirability of a generalized training device because it is always possible to use the parent system itself as the training device. There may, of course, be overriding considerations indicating that a generalized trainer should be developed. For example, the parent system may be packaged too densely for training purposes (in which case it may be practical to repackage the equipment as a trainer so that the trainees would have easy access to all component parts). Or, the power required by the parent equipment may exceed the power available in the designated classroom area. However, the greater the cost of the parent system, the easier it is to justify the cost of building a generalized trainer.

The desirability of producing a generalized trainer increases with the absolute size (and complexity) of the parent system. The size of the parent system is important because larger systems require fault isolation skills uniquely related to large systems. The complexity of the parent system is important because complex systems generally require special installations, special sources of power, special cooling, and even special secure facilities.

The more maintenance aids that the system incorporates, the less desirable it is to design and use a generalized training device to accomplish the training objectives rather than the parent system. The maintenance design of the parent system is important because it influences the complexity of required maintenance tasks and thus determines the overall maintenance burden. For example, complex systems that employ computer routines for automatic fault localization, or "digitalized" equipment requiring little or no alignment and calibration, impose a lighter maintenance burden on the technician than older systems in which logical fault isolation occupied the major portion of the technician's time.

ORGANIZATION OF NAVAL SCHOOLS

The present organization of Naval schools is very complex, involving many different schools, at many instructional levels, with diverse training objectives. However, only two classes of schools, Class A and Class C, are pertinent to generalized training device development. In general, Class A schools offer beginning and intermediate level instruction to train the technician to operate and repair systems in the family under consideration. They do not offer training on specific equipment (except when an older system is in use as a training vehicle). In contrast, Class C schools offer instruction and laboratory practice on specific systems.

Several years ago, technicians entering the Navy were processed through Class A school and then sent to a ship for on-the-job training on shipboard equipment. The objective of Class A schools was to equip the student with the appropriate skills so that, when supplemented by proper on-the-job training, he could perform fault localization and repair of electronic systems. At that time, Class C schools were attended primarily by personnel returning from shipboard duty to receive instruction in specific systems newly installed aboard ship. Class C schools were often poorly attended because individual ship commanders did not feel they could spare personnel from their maintenance force to return to school.

Several years ago, the Advanced Electronic Fields (AEF) program was instituted. Under this program, qualified candidates entering service who enlist for a six-year tour of duty are guaranteed both Class A training in an electronic field and one selected Class C school before being assigned to shipboard duty. Upon successful completion of this sequence, a Naval enlisted classification (NEC) is assigned. The Rating Control Officer in BUPERS assigns technicians to individual ships by NEC rather than rate, guaranteeing (in theory) that technicians are assigned to ships carrying the exact equipment on which they have been trained.

Class A school is further subdivided into A_1 and A_2 phases. In general, A_1 training focuses on techniques of operation while A_2 training focuses on maintenance. A four-year technician can obligate for two additional years at any point in the training cycle up to the beginning of A_2 and, in exchange, can attend A_2 plus one Class C school. Those technicians who do not obligate for the remaining two years are sent to the Fleet after A_1 as equipment operators. Class A schools are rate-specific; that is, there is a separate school for each electronic rate.

Prior to beginning Class A school, all student technicians attend a brief, general, course in electricity and electronics called "P" school. These courses are offered at San Diego and Great Lakes Naval Training Centers rather than at the rate-specific schools. The courses are self-paced, occupying from six to eight weeks, depending upon the proficiency of the student. At San Diego, computer-aided instruction is utilized for major portions of the course material.

One of the most difficult problems in training technicians to repair complicated electronic systems is bridging the gap between the theory and practice of electronics. The student must first acquire knowledge of basic electronic principles and then must learn to apply these principles to the maintenance of complex systems. It is unfortunate, perhaps, that the basic division of Class A and Class C training means that a student entering Class C school generally will not yet have seen complex electronic systems of the type he will maintain. Class C instructors quite often spend inordinate amounts of time helping students relate the theory they

have gained in Class A school to practical maintenance of the system. This trend is important to generalized training device development because it strongly implies the need for training vehicles at the A_2 level for teaching the organization of the equipment family in question, for illustrating the principles of logical troubleshooting, and for bridging the gap between theory and practice. The Electronic Technicians School at Treasure Island, California, solves the problem by offering a unique A_3 school course in which general training is given on radar and communications equipment prior to training on specific radar or communications system at the Class C level.

A change of the most significant importance is occurring at the present time. Almost all Naval schools are incorporating training in digital electronic technology, usually at the A_2 level. Traditionally, the A_2 phase of training has been associated with a specific family of equipment; for example, general sonar technology is taught at the sonar school. The advent of digital technology in virtually every family of electronics possibly will bring about a common school for digital technology as a "front-loading" course of instruction feeding the various Class A schools. For the time being, however, Naval schools likely will all offer training in digital technology, and their curricula for this phase of work will be virtually identical. Since this practice seems wasteful and costly, there is reason to believe that as digital technology becomes more and more common in military systems, the fundamental structure of the Naval schools/rates will be forced to shift.

SECTION III

METHOD

The data, conclusions and recommendations, equipment designs, and opinions contained in this report resulted primarily from a lengthy series of structured interviews with persons experienced in electronic research, development, procurement and training. The group included representatives of the several Naval Material Commands with responsibilities for the specification, test, and acceptance of electronic equipment for Naval ship and shore installations; industrial engineers and managers designing Navy equipment under contract; scientists conducting research studies in general support of maintenance techniques and training; and personnel assigned to the various Naval enlisted technical schools. The general survey method was supplemented by training situation analyses, rating and manpower analyses, equipment commonality analyses, and system engineering design as appropriate. A complete list of interviews conducted is included as Appendix II of this report.

PHASE I - METHOD

The Survey and Data Collection phase consisted of: (1) review of new developments in equipment technology, (2) identification, selection, and study of various equipment families, (3) formulation of future design trends for Naval electronics equipment, (4) review of existing generalized training devices, and (5) review of existing digital training devices. Each of these steps is discussed in greater detail in the paragraphs that follow.

REVIEW OF NEW DEVELOPMENTS IN EQUIPMENT TECHNOLOGY. A detailed study was made to identify the various dimensions of change for new Naval hardware. Interviews were conducted and specific equipments studied at each of the following commands: Naval Ship Systems Command, Naval

Ordnance Systems Command, Naval Air Systems Command, Naval Electronics Systems Command and Naval Ship Engineering Center. Discussions were held with cognizant program managers to identify maintenance features planned for inclusion in new systems. The following dimensions of change were selected for detailed treatment: solid-state circuitry, modularization, digital technology, standardization, multi-purpose and multi-mode displays, computer availability, automatic test equipment, life-cycle costing, functional packaging, lifetime spare parts, and total system design. Typical examples of each of the dimensions were identified and discussed with cognizant personnel. Particular attention was paid to standardization, computer aiding, and multi-mode displays because of their projected impact on new electronic systems.

Standardization. Reviews were conducted of the Standard Hardware Program and the Components/Equipment Standardization program. The objective of the Standard Hardware Program is to make available to Navy equipment contractors a standard set of functional modules from which a variety of electronic systems can be constructed. The program was considered important to the design of maintenance trainers of all kinds because a unique set of skill and knowledge requirements is created by this construction technique.

The Chief of Naval Material recently has directed all program managers to use SHP modules on all research, development and initial production programs whose aggregate cost exceeds one million dollars, or to submit convincing evidence that the SHP approach is simply not applicable to the equipment being procured. At the present time, it appears that most new electronic systems will conform to SHP standards.

The Components/Equipment Standardization program had its origin in 1965 when the Vice Chief of Naval Operations directed the Chief of Naval Material to establish standardization procedures extending to the concept formulation, contract definition, acquisition, and operational phases of developing and procuring new electronic systems. The objective was to standardize major commodity areas to reduce the proliferation of separate electronic devices and systems which then characterized Naval hardware.

The impact of the Components/Equipment Standardization program on training requirements and training device development will be to increase the commonality existing among electronic systems and to reduce the diversity of maintenance skills required.

Computer Aiding. A detailed study was made of computer-aiding techniques used to enhance the capability of new Naval ship and shore equipment. Digital computers are a central element of virtually every new weapons system; computer power substantially improves the capability of individual systems to process incoming information. The computer power may be self-contained, within a specific equipment family, or may be provided via a central computer complex.

The following computer applications were studied: (1) computers used for storage of information incoming from an external sensor system in real time and presentation to the operator in accelerated time, to allow the observation of sequences of events instead of events occurring in real time; (2) computers used to correct displays of sensor systems for motion contributed by own-ship's progress through the water; (3) computers used to assist operators in the "housekeeping" function--tagging, tracking, identifying and sorting target events; (4) computers used in conducting target motion analyses to determine the course, speed, and depth of targets contacted; (5) computers used to assist in classifying target objects in measuring and integrating target parameters; and (6) computers used for tactical correlation, to provide the "big picture." Each of these methods was studied carefully and later used in formulating trainer requirements.

Multi-mode and Multi-purpose Displays. In recent years, many multipurpose and multi-mode display systems have been developed by electronic manufacturing concerns because of the high estimated probability that such systems will be bought by the Navy for shipboard installation. Such displays are presently being developed for sonar systems, fire-control systems, command and control installations, navigation systems, acoustic warfare and countermeasures systems, and missile control and direction systems. The design characteristics of several such display

systems were studied to determine the commonality of design characteristics shared and the maintenance requirements generated. An assessment was then developed of the impact on generalized maintenance training devices of multi-mode and multi-purpose displays.

SELECTION OF EQUIPMENT FAMILIES FOR STUDY. Eleven families of Naval electronic systems were selected for detailed study, in keeping with the philosophy of generalized training devices presented in Section II of this report. These were: radar, sonar, torpedo guidance, command/control, communication systems, navigation, data systems, and four families of fire-control and missile direction systems. Representative equipments within each family were selected and studied to determine: (1) developmental trends and their meaning for generalized training devices, (2) philosophy of maintenance and repair planned for the new systems, (3) effect of standardization programs on equipments being designed, (4) planned use of multi-purpose and multi-mode display systems, and (5) planned techniques for computer aiding. In addition to studying typical equipments within each family, project personnel conducted interviews with personnel of the Material Commands during which the concept of generalized maintenance training devices was developed in detail and comments were solicited on the applicability of the approach to the equipment family in question. Discussion of each of the eleven families of electronic systems examined are contained in the next section of this report.

FORMULATION OF DESIGN TRENDS FOR FUTURE NAVAL ELECTRONIC SYSTEMS. The data collected on future system design were compiled and organized to provide a detailed assessment of long-term trends in system design. Four stages of change were identified: (1) traditional stage, (2) computer-aiding stage, (3) multi-purpose mode, and (4) central computer-control mode. Each of these four stages is developed in detail and illustrated in the next section of this report.

REVIEW OF EXISTING GENERALIZED MAINTENANCE TRAINING DEVICES. The design characteristics of the following generalized maintenance training devices were reviewed in detail: (1) Curtiss-Wright RMT-100A Radar Maintenance Trainer (Device 11DA), (2) Curtiss-Wright RMT-FC3 Fire Control Radar Maintenance Trainer (Device 11D13), (3) UHF/DF System Maintenance Trainer (Device 8D24), (4) Generalized Sonar Maintenance Trainer (Device 14E22), (5) Generalized Underwater Fire-control System Maintenance Trainer, and (6) Digital Sonar Maintenance Trainer (an adjunct to Device 14E22). The purpose of these reviews was to become generally familiar with the technology of implementation represented by this group of trainers to assess their relevance to new electronic systems. It was found that most existing generalized maintenance training devices utilize analog construction and, as such, serve nicely the systems installed today aboard ship. However, they will not help to meet the maintenance requirements generated by the new digital systems now beginning to make their appearance in the Fleet.

REVIEW OF DIGITAL TRAINING DEVICES. The design characteristics were reviewed of a series of digital logic and computer trainers. These devices are, in reality, generalized trainers because the relevant skill and knowledge elements transfer to digital systems regardless of family membership. The following systems were studied: (1) Univac Digital Trainer, (2) Bi-Tran 6 Digital Computer Trainer, (3) Basic Electronic Student Trainer (Devices 6B12 and 6B19), (4) Hickok Digital Logic Trainer (Device 6F11), (5) Logitran Models II and IV Logic Training Devices, (6) Digital Equipment Corporation Building Block Trainer, and (7) Pedagogics Digital Computer Laboratory. Each of these devices is either a computer trainer or a digital logic trainer; none were designed to serve the needs of digital electronic systems other than computers. However, the functional "building blocks" included in each device were listed and later checked against the Digital Systems Trainer design to ensure that each of the basic circuit types was represented adequately.

PHASE II - METHOD

The "equipment and training situation analyses" phase consisted of two parts: (1) analysis of the maintenance skill and knowledge requirements generated by existing and future electronic systems, and (2) analysis of the training situation at selected electronics training schools. Each of these activities is discussed in greater detail in the paragraphs that follow.

DETERMINATION OF SKILL AND KNOWLEDGE REQUIREMENTS

The method used in this study to determine skill and knowledge requirements for maintenance was to infer such requirements from the physical, functional, and constructional characteristics of the equipment. It is more common to determine skill and knowledge requirements for maintenance by performing a detailed task analysis of the various calibrations, replacement, and repair tasks performed by the maintenance technician. This is only possible, of course, for equipment that exists at present and for which some experience has accumulated (the inherent reliability of each section of an equipment directly determines maintenance requirements).

Generalized maintenance training devices, it may be recalled, themselves require lengthy developmental cycles; often up to five years is involved from conceptual design to installation in the training environment. Therefore, the only *existing* equipment for which skill and knowledge requirements were considered pertinent are those that have five or more years of useful life. In general these are only the newest systems being installed aboard Fleet units and in Naval shore installations.

A series of visits was made to each of the Naval Material Commands. Various program offices were identified that have cognizance over the development and test of new systems. Specific equipments were identified that are currently undergoing conceptual or engineering design or for which requirements now are projected. Information was collected on the planned maintenance philosophy, including projected techniques for repair, replacement, troubleshooting, and spares provisioning. Project

personnel attempted to at least identify every *major* electronic system being designed at present with the exception of highly classified intelligence and data-collection systems.

As noted earlier, a high proportion of new electronic systems are either entirely digital or are analog systems that widely utilize digital aiding, signal processing, and display techniques. Therefore, a narrower range of skill and knowledge requirements was identified than was true of older systems and than had been supposed at the outset of the study. Newly-installed and future systems commonly incorporate integrated circuits and adhere to a maintenance philosophy based on throw-away modules. As such, knowledge of the operation and function of individual circuit elements no longer is required, in contrast to analog and discrete-component electronic systems.

TRAINING SITUATION ANALYSES. Analyses of existing training situations were conducted at selected Naval enlisted training schools. Visits were made to 11 Naval schools offering 30 specific courses of instruction in maintenance of Naval electronics equipment. Complete training situation analyses were conducted at the Electronics Technician (Communications) schools at Great Lakes and Treasure Island, and at the Naval Torpedo School at Orlando. The objective of these analyses was to determine, for the existing curriculum, the applicability and utility of a Communications System Maintenance trainer and a Generalized Torpedo Maintenance trainer. A secondary objective was to determine the potential utility of these devices with modifications to the existing curriculum that will likely take place in the immediate future. A complete list of schools visited for training situation analyses is shown as Table 1.

Partial training situation analyses were conducted at the remainder of the schools visited to meet two objectives: (1) to determine the extent of present instruction in digital technology, and (2) to identify the specific phases of existing instruction for which training using the Digital Systems Trainer was indicated. It is important to note that present training in digital technology is responsive only to existing training requirements. Therefore, particular attention was paid to plans for incorporating digital technology instruction in the future, and to plans for utilizing existing digital training devices.

TABLE 1. LIST OF SCHOOLS VISITED FOR TRAINING SITUATION ANALYSES

COMMAND	SCHOOL (TYPE OF TRAINING)	RATE
Naval Schools Command Treasure Island	Electronics Technician (Radar) Electronics Technician (Communications) Electronics Warfare Technician	ET(R) ET(N) EW
Naval Schools Command Mare Island	Data Systems Technician Fire-Control Technician	DS FT(G)
USN Service Schools Command Dam Neck	Fire-Control Technician Electronics Technician (Navigation and Polaris/Poseidon)	FT(B) ET
USN Service Schools Command Great Lakes	BE&E Electronics Technician (Radar) Electronics Technician (Communications) Fire-Control Technician	 ET(R) ET(N) FT
USN Service Schools Command Naval Training Center, Orlando	Torpedoman's Mate	TM

A series of interviews was conducted with the Rating Control Officers in the Bureau of Naval Personnel for each of the enlisted ratings having important responsibility for the maintenance of Naval electronics systems. During these interviews, the training "pipeline" was discussed and documented for each important electronic rate. The discussions also covered qualifications for advancement in rating, methods by which school graduates presently are assigned to Naval ship and shore installations, and plans for future curriculum changes.

A series of informative discussions was held with the Commanding Officers and Enlisted Training Officers at several of the Naval schools visited. These are professional training personnel with impressive cumulative experience in the administration of Naval maintenance training. Their views on the future of Naval electronics training and maintenance of Naval ship and shore equipment are remarkably similar and, as such, are a particularly valuable source of information. As a final step in the analyses,

comments were solicited from enlisted instructors on problems encountered with instruction in digital technology and in the use of existing digital logic trainers.

PHASE III - METHOD

The "detailed design" phase of the project consisted of two parts: (1) analyses to identify the common circuit elements contained in a variety of computer and digital electronic sensor systems, and (2) system design of the recommended training devices. Each of these two steps is discussed in the paragraphs that follow.

COMMONALITY ANALYSES. All circuit and logic elements were identified that are contained in existing digital systems and in those being developed at present. About 20 characteristic types of circuit and logic elements commonly are found in digital sensor systems and in digital computers. As a consequence, it is possible to include most, if not all, common circuit elements in a single training device designed to serve the requirements of those systems. Up to 100 such individual circuit elements are found in analog equipment. The difference can be considered evidence of an increasing commonality of circuit elements as the gradual conversion takes place to digital technology. Thus, the concept of the generalized trainer likely has greater validity for digital electronic systems than it did with the older analog systems.

TRAINING DEVICE DESIGN. Three training devices were designed to the functional block level: (1) a Digital Systems Trainer, (2) a Communication Systems Maintenance Trainer, and (3) a Generalized Torpedo Maintenance Trainer. The Digital Systems Trainer is considered the most promising of the three and, as such, was designed in greater detail than the other two devices.

ADJUNCT - APPLICABILITY OF COMPUTER-AIDED INSTRUCTIONAL TECHNIQUES TO GENERALIZED TRAINING DEVICE DEVELOPMENT

A short, informal study was conducted to identify computer-assisted instructional techniques that are relevant to generalized *maintenance* trainer development. The following techniques were identified and studied:

(1) adaptive programming, (2) student control of practice conditions, (3) real-time performance measurement, (4) guided practice, (5) backward trouble shooting, (6) computer control of audio-visual aids, (7) introduction of malfunctions.

A major objective in this study was to determine the desirability of creating a hard-wire link between a digital systems maintenance trainer and a computer-aided instructional system. The hard-wire link is considered important because it allows the instructional device to assess the operational status of the training device and provides means of introducing malfunctions into the training device at a level of complexity appropriate to individual student progress. In addition, the opportunity is created for assessing student performance, continuously and in real time, and for providing feedback on progress to both the student and the instructor.

The computer-assisted instructional system at Fort Monmouth, New Jersey was studied. This facility is headquarters of the Army Signal Center and School; technicians are trained here to maintain electronic systems of approximately the same level of complexity as those maintained by Navy technicians. The program is considered experimental; it is being conducted in parallel with their regular program. A continuing evaluation is being made of student progress under the two conditions. This program has a unique aspect that is directly relevant to generalized training device design; students have the opportunity to obtain *"hands-on"* maintenance training under the continual guidance of a computer. A series of electronic training aids is provided for student use directly at the instructional station. Students also are provided with the actual test equipment that they will later use in the field. Each student is required to make voltage measurements and to observe waveforms using live circuitry, and to report the results to the computer. Feedback is then provided immediately on the correctness of the response. This method is not as elaborate as that envisioned for use with the Digital Systems Trainer in which a hard-wire link is envisioned. However, the work at Fort Monmouth represents the best effort made to date to provide practical (in contrast with classroom) computer-guided training in electronics maintenance and troubleshooting.

The computer-assisted instructional techniques studied do not appear to be related uniquely to digital systems, but the hardware commonality that exists between digital training devices and computer-assisted instructional systems means they could probably become one and the same device in the future. It is estimated that 80% or more commonality of hardware exists between typical computer-assisted instructional systems and digital training devices. Without stretching the imagination too far, it is possible to envision a classroom in which several students receive simultaneous, self-paced, automated instruction on digital systems maintenance techniques, involving "hands-on" practice with live equipment. It is difficult to imagine a more effective setting for electronics maintenance instruction.

SECTION IV

RESULTS AND DISCUSSION

This section contains the results of Phases I and II of the study; the results of Phase III, the training device designs, are contained in Section V of this report, "Conclusions and Recommended Training Characteristics." This section includes: (1) an overview of the present state of design technology of electronic equipment, (2) a description of each of several dimensions of technological change, (3) a discussion of long-term trends in system design, (4) a series of discussions on equipment design changes and training device requirements in 11 selected equipment families, (5) the results of training situation analyses conducted at Naval enlisted training schools, including diagrams of the training "pipeline" for several critical Naval ratings, and (6) a discussion of automated-instructional features applicable to generalized training devices.

OVERVIEW OF THE PRESENT STATE OF TECHNOLOGY

At the present time, a quiet electronic revolution is taking place that will bring about major design changes in military electronic systems. These design changes likely will force reorganizations of both the basic structure of shipboard maintenance and the content of present training curricula. These changes, in turn, will influence and determine the development of training devices, both generalized and equipment-specific.

Approximately 15 years ago, solid-state electronic devices began to permeate the non-military electronic market. About five years later, large non-military systems appeared, primarily computers and data-processing equipment, built entirely of solid-state components. It was predicted at that time by Naval personnel planners that the impact of solid-state electronics on Naval manning and training requirements would begin to be felt in about four years, or about six years ago. However, large systems composed entirely of solid-state devices are just now being installed in Naval ship and shore installations in large numbers. The delay was due

to a variety of factors, probably the most important of which were the more stringent requirements for shock and environmental protection and the longer lead times involved in producing large Navy systems. Often four years elapsed from conceptual design to readiness testing. Whatever the complex of reasons, the long-awaited period of change has begun and appears to be gaining speed.

The consensus among personnel planners was that the onset of the new technology would have two major effects: (1) a significant reduction in maintenance manpower requirements due primarily to the vastly improved reliability of solid-state circuitry, and (2) a reduction in skill levels required for electronic maintenance due to the throw-away maintenance philosophy. These two effects no doubt will occur, and probably quite soon, but to date there is little visible evidence that these two factors are operating. Probably the most important manifestation of the new technology thus far is the addition of course work in digital logic within the Class A courses at most Naval electronic schools.

A third, and unpredicted, effect now also seems likely; a requirement is being created for a technician whose level of skill and knowledge far exceeds that represented by today's technicians. This "super technician" is needed to cope with system-level problems. Instead of a general downgrading of skill and knowledge requirements, it is believed that a fractionation of requirements is developing in which the majority of simple, throw-away maintenance will be done by lower skill-level technicians and the system-level maintenance by the super technician.

In about two years, the first large systems constructed totally of microelectronic components will be installed in the Fleet. At this time, the first significant reductions in maintenance manpower requirements are likely to occur. The total number of technicians required to maintain the full complement of a single ship's equipment can be expected to be reduced by half or more. It would seem, for the first time in many years, that the formidable problem of shipboard maintenance can perhaps be solved.

DIMENSIONS OF CHANGE

The following technological advances are discussed in the paragraphs

that follow: (1) solid-state circuitry, (2) modularization, (3) digital technology, (4) standardization, (5) functional packaging, (6) general-purpose displays, (7) computer aiding, (8) automatic test equipment, (9) life-time spare parts, (10) life-cycle costing, and (11) total system design.

SOLID-STATE CIRCUITRY. Undoubtedly, the single most important change in electronics in recent years is the development of solid-state circuitry. There has been a gradual evolution from vacuum tubes to transistors to integrated circuits to medium-scale integration to large-scale integration. These developments are now beginning to have a profound effect on personnel and training requirements for maintenance of shipboard systems because the smallest replaceable unit of electronic hardware now lies above the "circuit" level; that is, the detailed principles or operation of individual circuits are no longer at issue in fault localization and repair. The change from vacuum tubes to transistors was not an important factor in the reduction of troubleshooting training requirements; transistors only replaced vacuum tubes on a one-for-one basis. Instead of a reduction, an additional training requirement was created--the need to understand the operation of transistors. It was the development of integrated circuits that waived the requirement to understand the operation of individual components, requiring only that the technician deal with the input-output characteristics of circuits. No new training requirements will be created as the size and complexity of the integrated block increases in the future, because the technician will still deal with the input-output characteristics of the unit, regardless of size. However, as the size and complexity of the block of circuitry increases, the function that it performs will more likely be identifiable with a unit or subunit function. This effect will perhaps simplify logical troubleshooting for those systems still requiring it.

MODULARIZATION. Modularization has a significant impact on maintenance because it allows the technician to deal with the input-output characteristics of modules, and to substitute good modules for bad to correct a malfunction. If the characteristics and size of the module are such that it can be produced inexpensively, the system designer can adopt a throw-away maintenance philosophy, one within which the isolation and repair of individual components is not required. Spare modules are kept aboard ship, often furnished and packaged as a part of the parent equipment. Modularization

plus vastly improved reliability of modules has, in some cases, allowed lifetime spare parts to be packaged with the original equipment. The additional impact of this development on maintenance logistics is obvious.

DIGITAL TECHNOLOGY. The advent of digital technology has produced two primary effects: (1) it has created a need for training in digital logic and in the organization and maintenance of digital equipment, and (2) it has increased the commonality of circuitry and thus of maintenance requirements across families of electronic equipment. A shift register in a sonar set operates identically and creates identical maintenance requirements as a shift register in a fire-control system. In short, the expected extent of transfer from one digital system to another is very high since basic logic and design elements are shared. The development of digital technology will be responsible, in large measure, for the predicted reduction in diverse knowledge requirements for electronics maintenance.

STANDARDIZATION. Essentially, standardization increases the physical or constructional similarity of electronic systems. As Naval systems become more standardized, the commonality of circuitry increases, thereby increasing the transfer of learning from one system to the next and decreasing the diversity of specific skills required for maintenance of different systems.

The Components/Equipment (C/E) standardization program had its origin in 1965 when VCNO established 19 subcommittees under the parent Navy Logistics Support Steering Committee, to describe and analyze Navy logistic support and to recommend remedial actions as problems were identified. Also, at about that time, the Logistics Management Institute prepared a report in which large numbers of equipment and components were identified that are peculiar to a single ship or a small number of ships. Additional studies by several of the subcommittees, the Naval Ship Systems Command, and the Naval Supply Center, Mechanicsburg, further highlighted the problem by pointing out that there were approximately 175,000 equipments and components with approved part numbers, of which 50% were installed in four or fewer ships, 27% in five to 19 ships, and only 23% in 20 or more ships. Based on this information, VCNO directed the Chief of Naval Material to establish a standardization program extending to the concept formulation, contract definition, acquisition, and operational phases of

developing and procuring Naval electronic systems. By direction, standardization was to extend to materials, processes, services, and parts.

In response to the direction cited above, the Chief of Naval Material prepared NAVMAT Instruction 4120.97, directing each of the Systems Commands and Program Managers to develop a plan for standardization of all equipment under their administrative cognizance. Specific guidelines were provided and specific content suggested for the plan. Each Systems Command was directed to develop indices to reflect the current status of standardization in major commodity areas and to provide for periodic reporting of progress using the indices developed. In response to the NAVMAT Instruction, each of the Systems Commands and Program Managers, including Naval Training Device Center, prepared and distributed comprehensive standardization plans and methods for progress review.

It likely will take several years before the major impact of this standardization program is felt. But, it can be safely predicted that the proliferation of separate electronic devices and systems which characterized Naval hardware development during the 50's and 60's will give way to fewer, more comprehensive procurement programs, including many items of standardized hardware at various levels of complexity. The impact of this program on training requirements and training device development will be to increase the commonality existing among electronic systems and to reduce the diversity of maintenance skills required.

The Standard Hardware Program (SHP) is a module standardization project that will make available to electronic designers a wide selection of standardized plug-in modules. These modules will serve as building blocks from which systems engineers can construct a variety of complex systems. The SHP had its origin in the development of the Mk 84 Polaris Fire-Control System about 10 years ago. This system was designed and constructed utilizing over 6,000 modules, representing only 50 separate types. There was no effort then to minimize the number of separate module types. The configuration of the modules was established by the Naval Avionics Facility, Indianapolis (the modules have now become known as NAFI modules). The quality control and reliability testing of various module types is performed by the Naval Ammunition Depot, Crane, Indiana.

Since the SHP Program began, it has progressed to the point where over 300 standardized modules of known reliability now are available to industry. The modules are in use in over 20 major electronic systems, including the new IDNA sonar system, which alone utilizes 9,500 modules per system. NAFI personnel predict that over five million modules will be in service in the Fleet within three years.

The SHP Program has grown steadily and now assumes mature status. A complete line of documentation is available including a Program Manager's guide, a requirements manual describing the use of the modules, and a four-volume series of specific design guidelines. Ancillary developments include computerized programs for back-plane wiring, guidelines for packaging using standardized modules, and computerized electronic design based on the input-output characteristics of all modules.

Management of the SHP Program recently has been transferred from SSPO to NAVELEX; the basic charter of NAVELEX includes responsibility for all Naval specifications and standards programs. CNM has instructed NAVELEX to coordinate with all Systems Commands and Program Managers to prepare a directive requiring the use of SHP modules on all R&D and initial production programs whose aggregate cost exceeds one million dollars. Essentially, each Program Manager must either elect to use SHP modules for any new system or must demonstrate, to the satisfaction of NAVELEX engineers, that the SHP modular approach simply is not applicable to the equipment being procured. Thus far, Program Managers have specified SHP techniques for most new procurements. If this trend continues, and there is every reason at present to believe it will, the proliferation of specific types of Naval systems will decrease dramatically, creating a vast base of identical maintenance requirements for many types of electronic systems. These developments will in turn force a reexamination of the present Naval rating and training structure, and will force a critical examination of training device construction techniques.

For the interested reader, the appendix of this report describes the design and construction details of SHP modules and their applications. The information presented demonstrates the level of sophistication achieved thus far on the SHP Program.

FUNCTIONAL PACKAGING. Functional packaging is an interesting and important design trend in which individual circuit elements are combined and physically packaged along functional lines; each block of electronic hardware represents an identifiable function which is, in every case, relatable to its role within the parent equipment and to the purpose/mission of the parent system. The functional package is the smallest replaceable unit, but unlike SHP modules that are identical in size, functional modules vary according to the complexity of the function represented. Essentially, each unique, definable function performed by a subsection of equipment is given an analog in hardware.

A comprehensive program is being pursued by the Naval Electronic Laboratory Center, San Diego, California. This laboratory is studying the problems involved in large-scale packaging of blocks of electronic circuitry. Thus far, they have packaged blocks as large as an entire receiver in throw-away modular form. At the present time, this type of packaging is very costly and not likely to be feasible for large Naval systems. But, as quantity production drives the cost of individual units down, a point will be reached where this type of packaging might be adopted.

The implication of functional packaging for maintenance training, and for training device development, is that each parent equipment becomes, potentially in itself, a training device, providing the means for the maintenance technician to learn the functional organization of the equipment and to identify specific blocks of equipment that perform each of the functions learned. Transferring from a block diagram of a complex system to actual hardware has proved difficult for student trainees because, with present hardware, no physical analog exists for a function under study. Specific equipment functions often are distributed through many units or even through several equipment cabinets.

There is a trend toward increasing size of the smallest replaceable unit of electronic hardware. As production efficiency reduces unit costs, the amount of hardware included in the throw-away module can be expected to increase significantly.

MULTI-PURPOSE AND MULTI-MODE DISPLAYS. In the last few years, at least 15 multi-purpose and multi-mode display systems have been developed by Navy laboratories and electronic manufacturing concerns. Most of these developments have been sponsored by the various companies at their own expense because of the high estimated probability that such systems will become candidate items for shipboard installation. In general, the displays have been designed to operate in conjunction with a computer system; but at the same time, they usually have a buffer memory or associated buffer computer to develop the various display formats. The display operator essentially can select from among a variety of available formats depending on the tactical and environmental conditions that exist at the time of selection.

Multi-mode and multi-purpose displays presently are being developed for sonar systems, fire-control systems, command and control installations, navigation systems, acoustic warfare and countermeasure systems, and missile control and direction systems, as well as for a variety of non-military applications. The surprising thing about all such displays is their design commonality; in many respects they are identical to one another. The maintenance requirements which they generate also are highly similar. At the present time, these devices are the responsibility of the Data Systems Technician (DS) rate. However, they will soon become the concern of many Naval ratings. As such, their presence aboard ship strongly implies the need for maintenance training on these displays in the very near future.

The importance of multi-mode and multi-purpose displays for generalized training device development is simply that future trainers for operation or maintenance should unquestionably contain general-purpose, computer-driven displays as an integral part of the device design. It is probably safe to predict that five years from now, virtually all major electronic systems installed aboard ship or Naval shore installations will include one, and likely several, general-purpose displays.

COMPUTER AVAILABILITY. One of the most important dimensions of change is the increasing availability of computer power aboard ship. At the heart

of virtually every new weapons system there is a digital computer to organize and process large amounts of information from the sensor systems. Computer power substantially improves the capability of individual sensor systems to process incoming information. Examples of several types of computer aiding are given in the paragraphs that follow.

Computers can be used to store incoming sensor information in real time, up to an amount of time determined by available memory capacity. Then, sequences of sensor events are called out onto the general-purpose display, so that the operator can make a time-dependent assessment of the presence and nature of an intruding target. As a result, the operator can observe sequences of events instead of single events that occur in real time, and then derive classification clues that enable him to categorize the target as threatening or not.

Computer power can be used to correct displays of sensor systems for motion contributed by own-ship's progress through the water. Inputs can be taken from the Ship's Inertial Navigation System (SINS) or other stable platform and integrated into accurate values of speed-along-course and speed-across-course. The computer can then cause the display to represent a segment of geography locked to real-world coordinates rather than being locked to a moving platform (own-ship). This capability, in turn, permits the motion properties of targets to be assessed independently of the motion contributed by own-ship, again providing valuable classification information.

The availability of computer power is invaluable to sensor system operators in the "housekeeping" function--tagging, tracking, identifying, and sorting target events. Computers can also help in keeping track of the modes of operation in use, the status of important controls, information on expected conditions of propagation, or other important data that the operator needs to perform his job. When the computer is used in conjunction with a general-purpose display system, information can be portrayed in alphanumeric form.

Computer power is invaluable in conducting target motion analyses to determine the course, speed, and depth/height of targets contacted. This

function is typically accomplished by tracking, that is, by superimposing an electronic cursor over the indicated target position on the display. Then, the computer assesses the location of the electronic cursor in real time and computes the necessary quantities in accordance with stored formulas for processing target information. This type of operation is characteristic of modern fire-control systems, whether coupled to radar inputs for surface-to-air missile direction, or coupled to sonar inputs for underwater battery control.

Computer power can materially assist in classifying target objects by measuring and integrating a variety of parameters which characterize targets of known types. For example, underwater targets detected by sonar systems can be classed as submarines, surface ships, biological sources, etc., by measurement and analysis of category-defining parameters and the correlation of measurements along each of the parameters. In some clue correlation systems, the operator enters a judgment along each of various clue dimensions and the computer combines these into a probabilistic target decision in accordance with stored instructions.

Tactical correlation, providing the "big picture," is an important computer function aboard ships, usually cruisers or aircraft carriers, with command or operational-control systems. Tactical correlation typically is accomplished on computer-driven, general-purpose display systems that show a geographic field with inputs from own-ship's sensors, aircraft sensors, and other surface ships or submarine sensors.

The examples of computer aiding, given in the paragraphs above, are but a few of the many examples of computer power in Naval systems that could be cited. It can be safely predicted that both the amount of computer power available and the extent of computer aiding will increase significantly in the next few years.

AUTOMATIC TEST EQUIPMENT. Virtually every new system being designed incorporates an automatic system for fault localization, usually integrated with and driven by the shipboard computer. These automatic systems are capable of localizing faults down to the level of 20 to 50 modules at the present time. In the near future, localization to the individual module

is likely to become feasible. These automatic systems typically conduct a preprogrammed sequence of system-status tests at critical, preselected points. The points are interrogated by the computer sequentially and continuously, in real time. It is obvious that these automated systems can provide significant reductions in maintenance manpower requirements.

LIFE-CYCLE COSTING. Military hardware has, to date, been procured on a system-by-system basis, one in which the cost estimates of the various bidders are considered for the initial procurement only. It has recently been determined that the life-cycle cost of an electronic system is on the order of ten times its initial cost. Therefore, system planners have recently turned to a cost analysis spread over the entire life of a system as a basis for evaluating the approaches of various contractors. Now, a contractor will be favorably considered whose initial costs are higher but whose system includes a logistic support package that brings down the life-cycle cost. This approach encourages bidders to add features to the equipment that will assist in maintaining the system on-line over extended periods.

TOTAL WEAPONS SYSTEM DESIGN. Until now, major combat systems have been designed and procured in pieces; separate suppliers have been responsible for various components of the total system. This practice has led to a number of system interface design problems as well as many communication problems among suppliers. The DD-963 Destroyer Procurement Program is one in which a single supplier, Litton Systems, Inc., is responsible for the hull and its contents. They are procuring the separate subsystems from different contractors but are still held responsible by the Government for the performance of their subcontractors. Rather than the Government, the lead contractor assumes responsibility for weapons system integration.

Total weapons systems design is particularly important when a general-purpose computer is planned as the heart of a weapons system and is the focal point of integration for the entire system. In prior years, a variety of "interface boxes" were required to couple the outputs of sensor systems into the central computer complex. These devices typically were analog-to-digital converters because the sensor equipment was analog and

the central computer was digital. By designing for the total system, the need for these interface boxes is eliminated because their design is subsumed by the sensor system contractor. It is his responsibility from the outset to design the sensor equipment outputs so that they will interface appropriately with the central controlling elements of the weapons system.

The dimensions of change described in the paragraphs above combine to produce a series of long-term trends in system design that are important to the structure of Naval training and to the design of training devices, both generalized and system-specific. These trends are discussed in the section that follows.

LONG-TERM TRENDS IN SYSTEM DESIGN

Four stages of change in shipboard equipment design have been identified as a convenient means of describing long-term trends. For convenience, these are called: (1) traditional stage, (2) computer-aiding stage, (3) multi-purpose mode, and (4) central computer control. Each of these four stages is discussed in this section and illustrated by a diagram showing the organization of shipboard equipment at each stage.

The "traditional" stage, prevalent from 1944 to 1966, was one in which sensor systems were procured and installed as independent units. Each sensor system is served by a transducer that converts incoming signals to electrical energy. Sensors are radars, communications systems, sonars, navigation systems, countermeasure sets, etc.; three such sensors are shown in Figure 1.

A box labeled "display control" is shown internal to Sensor 1 and Sensor 2, indicating that the displays are specialized and dedicated, and that control of the system is accomplished at the sensor system itself, usually through a control console. The dotted line from Sensor 1 to Sensor 2 indicates that the output of one sensor can feed the input of another, as in the case of a radar feeding a fire-control system. In that event, of course, the system receiving information would not correctly be termed a sensor. The dark arrow to the "director" box indicates that the system might feed a weapons-guidance subsystem, such as a torpedo-director or a

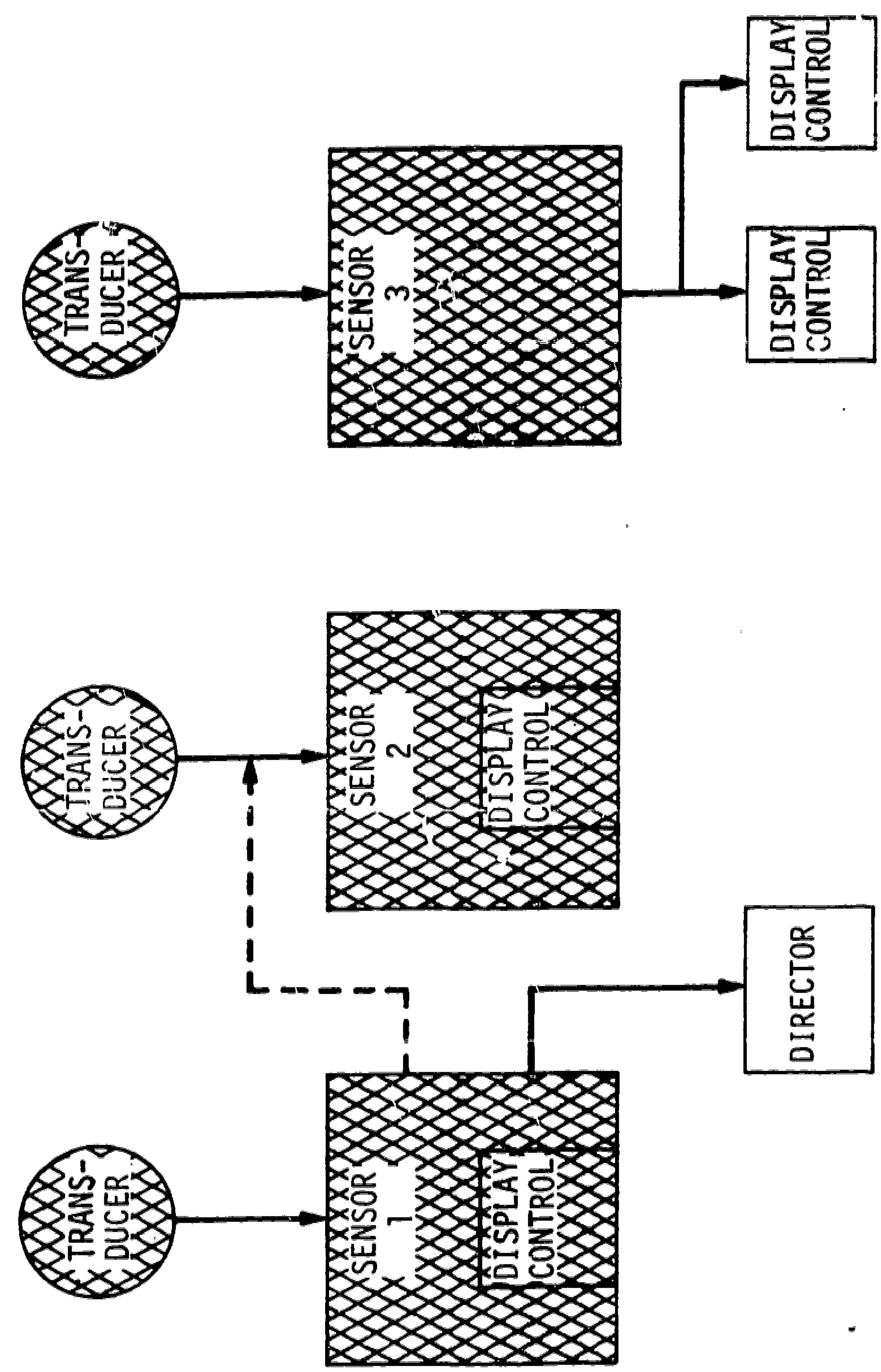

Figure 1. Design Trends in Shipboard Electronic Equipment - Traditional Stage (1944-1966)

guided-missile director. The two display control boxes fed from Sensor 3 indicate that it is possible to have a single sensor feed two or more indicator stations. Typically, surface-search radar systems installed aboard ship are arranged so that the outputs of the radar sensor equipment can be viewed at a remote indicator installed on the bridge, in CIC, etc. All equipment shaded in the diagram is considered part of the sensor system complex; no data-processing equipment is considered in the traditional stage.

The "computer-aiding" stage, prevalent from 1966 to 1974, is more complex; it represents the present stage of design. The organization of equipment during this stage is illustrated in Figure 2.

Four sensor systems are shown shaded diagonally; data-processing equipment is shaded vertically and horizontally. Sensor 1 has internal display and control capability and communicates with internal data-processing equipment through an analog-to-digital converter system. The "data-processing" box shown below Sensor 1 indicates the presence of central data-processing equipment that does not link to the sensor system. The dotted line to Sensor 2 indicates an information input from Sensor 1 to Sensor 2 such as that from a sonar to an underwater fire-control system. The dark arrow to "director" indicates a guidance capability.

Sensor 2 has internal display and control capability but communicates with central data-processing equipment through an external analog-to-digital converter. Sensor 3 also has internal display and control capability but can deliver its outputs to external display and control equipment. It communicates with central data-processing equipment through an analog-to-digital converter, but the data-processing equipment is fed from own-ship's stable reference, such as pitometer log, SINS, or doppler sensor. Sensor 4 does not have internal display and control equipment but utilizes peripheral indicators for this function; otherwise, it is identical to Sensor 3.

In the computer-aiding stage, the absolute size of the sensor boxes has decreased from the traditional stage, indicating that less

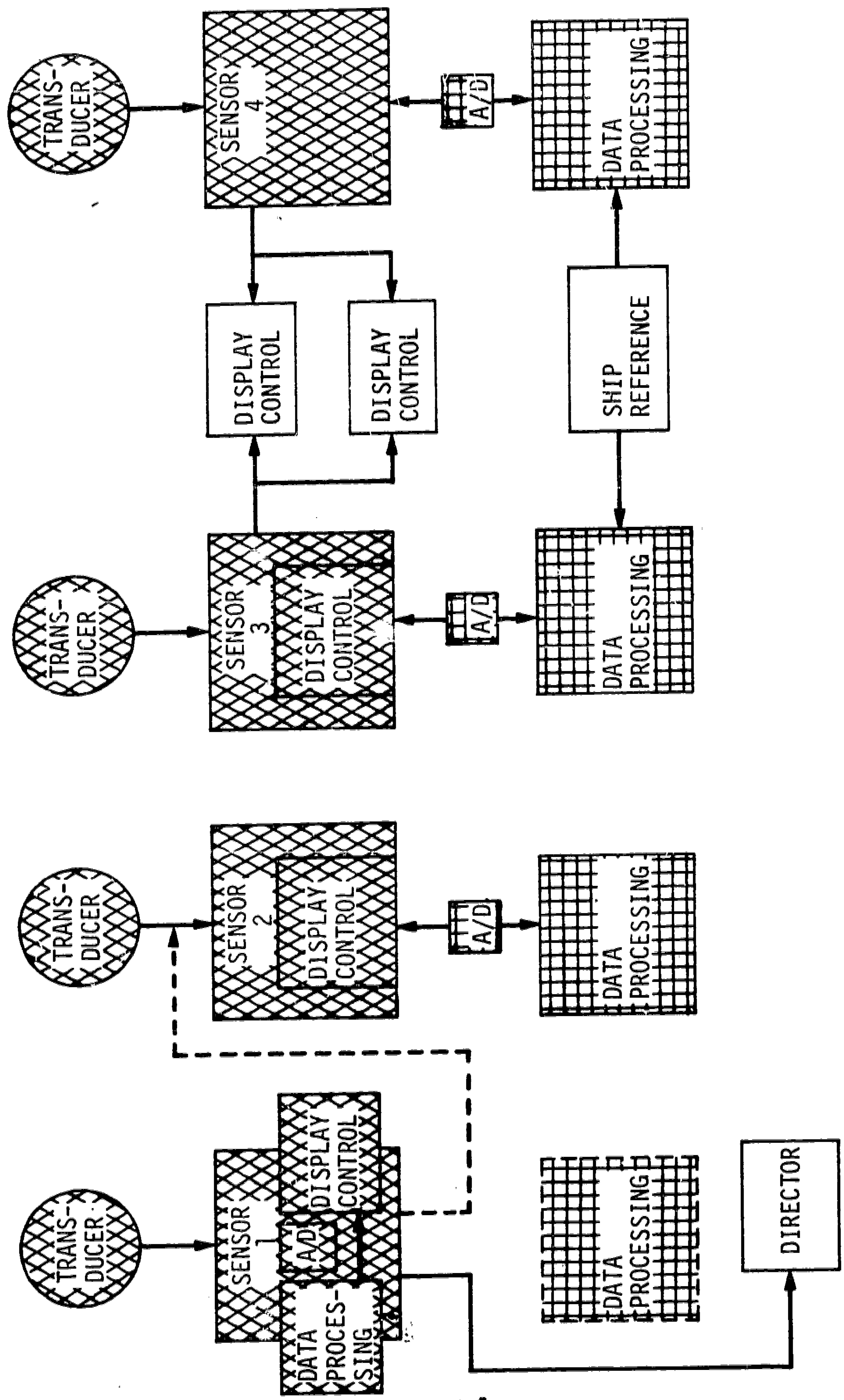

Figure 2. Computer Aiding Stage (1966-1974)

44

equipment now is included as part of the sensor systems. Data-processing equipment has appeared for the first time but is not yet comparable in size to the sensor equipment.

The "multi-purpose mode," projected for the period 1974 to 1980, begins to show the influence of total weapons system design. The organization of equipment during this period is illustrated by Figure 3.

At the heart of the multi-purpose weapons system is the central computer complex. It is called a "complex" because it consists of several small computers operating side by side rather than a single, larger, computer. Each of the boxes representing Sensors 1 through 4 is smaller than in the previous stages, indicating that the absolute bulk of equipment identified with each sensor has decreased. Of particular interest is the fact that the display consoles are now separated from the sensors; rather than being dedicated, the displays are now multi-purpose. The sensor equipment consists only of transducers and analog processing devices. The sensors are controlled by the central computer from commands initiated by the operator at the display console. These commands arrive and leave the central computer through analog-to-digital converters. Weapons direction is accomplished by the central computer. Ship's reference information is fed to each computer in the central complex.

The essential feature of the multi-purpose mode is that, for the first time, the sensors are unmanned, except for the fact that the display console serving a particular sensor may be physically adjacent to the sensor it serves. The display consoles are multi-mode or multi-purpose control stations, probably manufactured by one of the data-processing companies. Contained in the memory of the central computer complex are a variety of display formats, any one of which can be selected by the operator from the display console. Information from the sensors can be displayed on the consoles in any one of the available formats. The vast majority of weapons systems now in the planning stages are of the "multi-purpose mode" type.

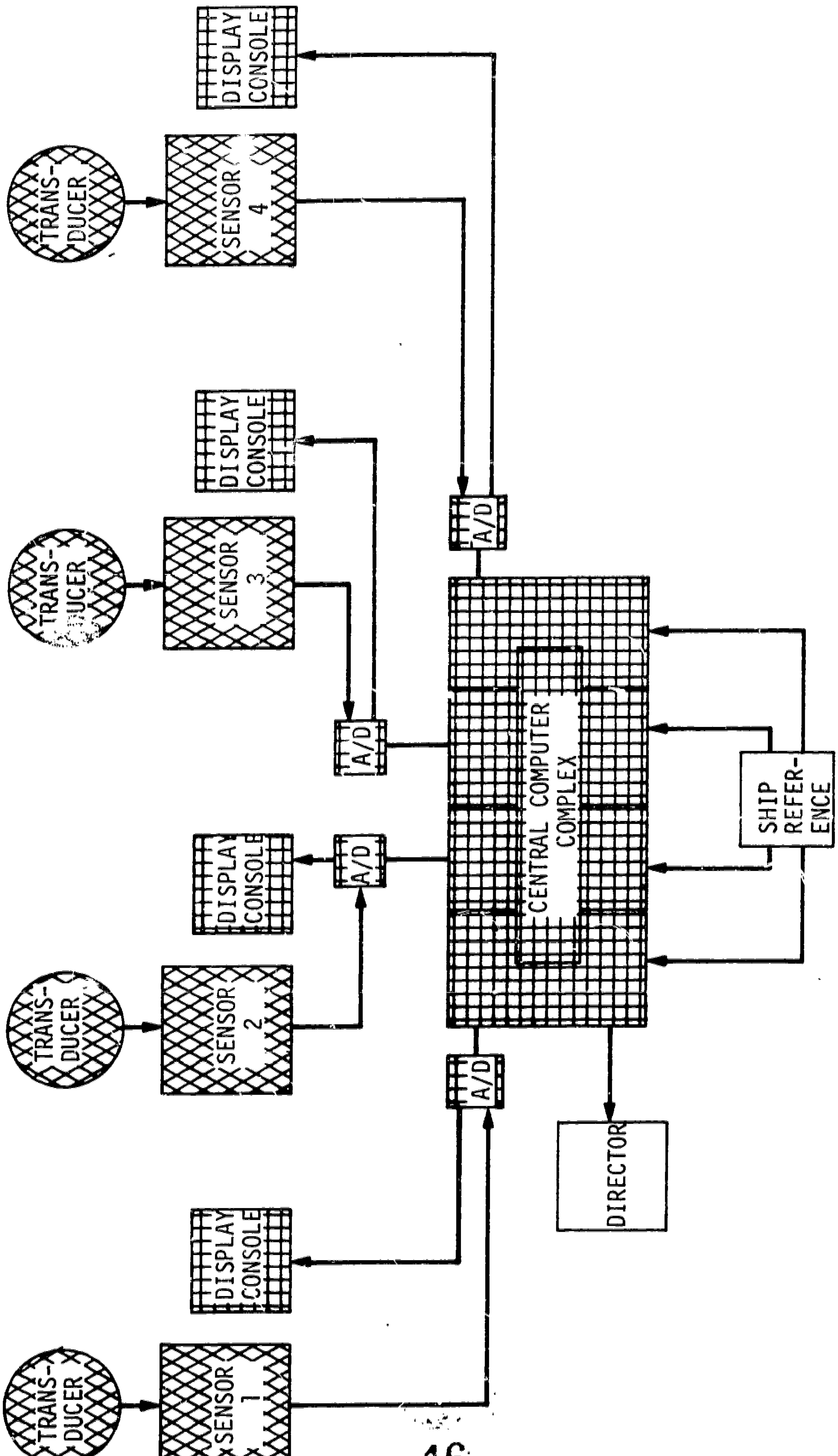

Figure 3. Multi-Purpose Mode (1974-1980)

The "central computer control" stage is projected to begin about 1980. The organization of equipment during this stage is shown in Figure 4.

The sensor equipment with its associated transducers now has the smallest gross size of any stage described. The sensors are unmanned and might be physically located near the transducer rather than in the shipboard control spaces. A single, central computer is prominent; the analog-to-digital converter equipment has migrated into the central computer. Weapon direction is the responsibility of the central computer; ship reference is fed directly to the central computer. A section of the computer is devoted to the development of the display formats, any one of which is available at any display control station. The stations are identical; it is arbitrary which station is sonar, fire-control, radar, etc. The display control stations probably are located together physically in CIC, together with navigation and ship-control stations and equipment. Thus, the entire ship's tactical mission and operation can be executed successfully from a single space aboard ship.

The important aspect of the central computer control stage is that the majority of the system is composed of digital, data-processing equipment and associated displays, shown vertically. Each sensor consists only of the remaining analog equipment, the portion that cannot be "digitalized" because of high power, low frequency, or other special requirements.

The four trends described in this section together illustrate the predicted direction of Naval electronic systems. It should be obvious that these trends have major implications for personnel and training requirements and for training device design. The most important implication for personnel and training requirements is that a far greater need will be created for technicians with training in data-processing systems, particularly in digital systems repair. The Data Systems Technician (DS) rate is expected to grow exponentially. Conversely, the need for sensor-related technicians will decrease; fewer sonar technicians, fire-control technicians, electronic technicians, and the like will be needed (we may not need fewer in the absolute sense because of a generally expanding

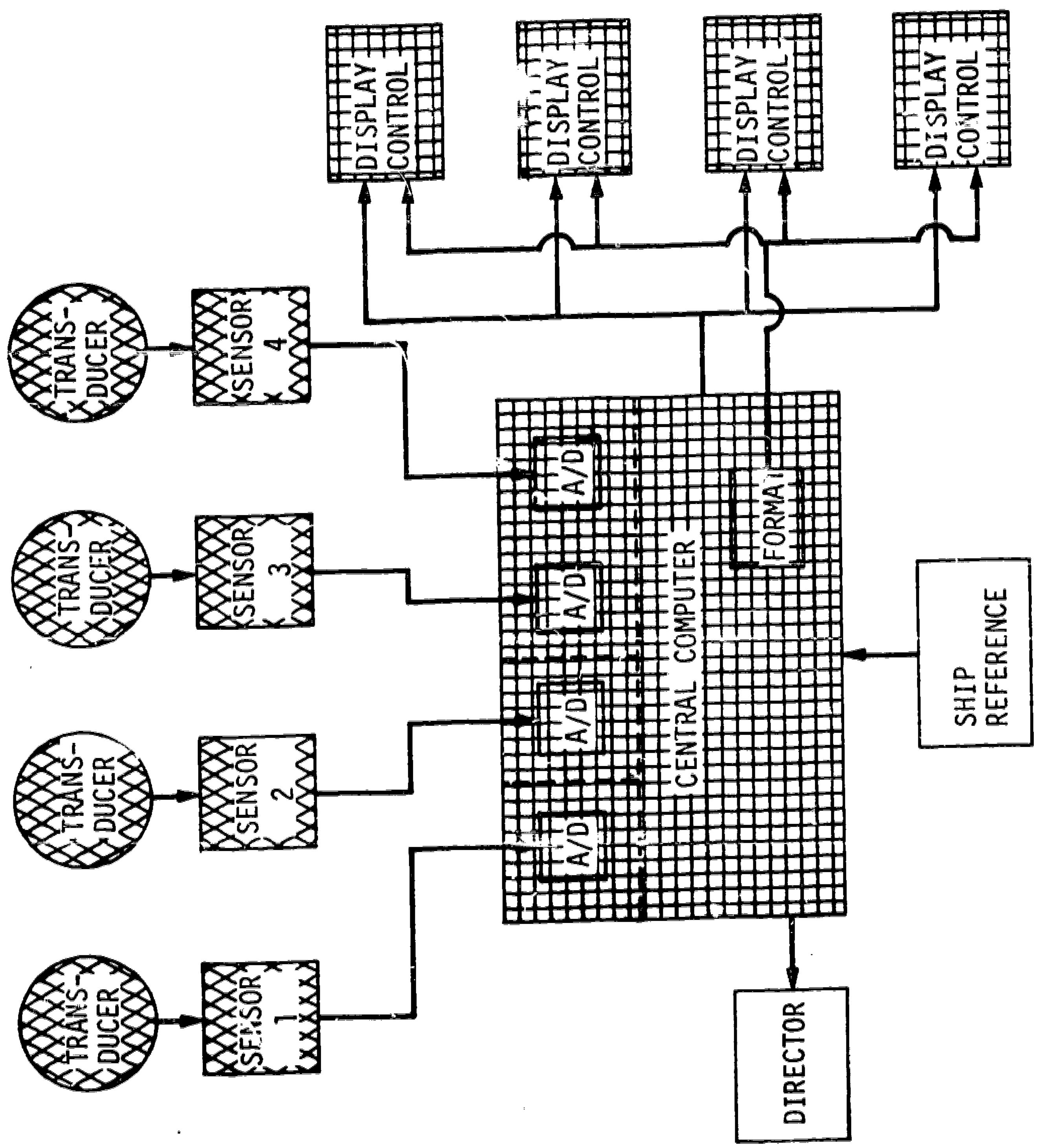

Figure 4. Central Computer Control (1980 -)

electronic capability, but rather proportionately fewer will be needed). It is possible that many electronic rates that exist at present may be discontinued or be merged into a subsection of data-processing technology. Technicians responsible for repair of data-processing equipment will require training in digital logic and electronics down to the functional block level. Likely no training in detail electronic design will be required for the bulk of the technician force. As described previously, however, a few super technicians will be required, primarily to deal with complex, system-level localization and repair problems when they occur.

The impact of these long-term trends on generalized training device design is that commonality among equipments of a family will decrease in future years and commonality across families will increase substantially. This conclusion emphasizes the need for new training aids and devices to teach digital systems maintenance and operation. Generalized training devices that are family-specific likely will be required only for electronic systems that do not lend themselves readily to implementation with digital technology. It should be borne in mind, however, that the analyses leading to the above conclusions were based on the study of a selected group of electronic systems, primarily large electronic systems for Naval ship and shore installations. The conclusions do not extend to generalized training devices for electromechanical equipment or equipment uniquely related to a single vehicle, such as airborne electronic devices. Nevertheless, it is safe to conclude that future requirements for training devices, both generalized and equipment-specific, will become increasingly digital in nature, if not entirely digital.

EQUIPMENT CHANGE AND TRAINING DEVICE REQUIREMENTS IN SELECTED EQUIPMENT FAMILIES

This section of the report examines 11 selected groups of Naval electronic systems with respect to five issues: (1) developmental trends and their meaning for generalized training devices, (2) philosophy of maintenance and repair for new systems, (3) effect of standardization programs on equipments being designed, (4) availability of generalized training devices, and (5) implications for generalized maintenance training device development.

RADAR. Radar systems, as a class, are designed to transmit and receive energy pulses at very high frequencies, typically 300-30,000 MHZ. At these frequencies, the nature of electronical energy is such that special electromechanical devices must be used to generate energy and to guide the energy once generated. By their basic nature, then, radar systems are less amenable than other systems to digital and modular techniques; their philosophy of maintenance has remained essentially unchanged over the years. A few digital "add-ons" have been designed to process radar signals returning from target sources. These processors create a need for training Electronic Technicians ET(R) in digital techniques but do not reduce maintenance requirements from existing and near-future radar systems.

There are several excellent radar training devices in use today. Device 11B8 (Radar Maintenance Trainer 100A, Curtiss-Wright Corporation) is the most important of the existing trainers. In our view, it is an excellent device that can be used for all radar systems training except in digital signal processing. The existing training devices, considered together, adequately fill the need for generalized maintenance trainers in the radar area; no additional training device development seems indicated.

SONAR. In sharp contrast to radar systems, sonar systems are now being designed that are totally solid-state and primarily digital. It is highly likely that all future sonar systems will be designed using digital computers and general-purpose display systems. The two newest submarine sonar systems are heavily digital, use SHP construction techniques, and employ automatic fault localization. The newest destroyer sonar is primarily digital, uses modular (not SHP) construction techniques, and employs automatic fault localization. Many major retrofit packages are being designed that use digital technology and require maintenance skills related to that technology.

A generalized sonar maintenance trainer (GSMT) is in use at the sonar schools at San Diego, California, and Key West, Florida. A digital adjunct has been recommended to NTDC for procurement, designed

to serve the maintenance requirements of digital sonar systems. The digital adjunct is, in essence, a digital logic trainer, one of a family of approximately 10 similar logic trainers. No additional training device development is indicated to serve the training needs of sonars now installed in the Fleet. However, there appears to be a requirement for training in digital technology at the systems level that cannot be met with existing or proposed digital logic trainers.

FIRE-CONTROL. The fire-control family consists, primarily, of four main groups of electronic systems: (1) equipment installed aboard FBM submarines associated with the Polaris and Poseidon weapons systems, (2) equipment installed aboard destroyers associated with the Terrier, Tartar, and Talos surface-to-air missile systems, (3) equipment installed aboard FBM and nuclear-attack submarines associated with the launch and control of torpedoes and the SUBROC missile, and (4) equipment installed aboard destroyers associated with the ASROC, anti-submarine missile system.

The Polaris and Poseidon fire-control systems are large, digital data-processing devices. They are built to SHP standards, have automatic test equipment, and utilize extensively elements of the new technology. The maintenance requirements generated by these systems focus on digital logic, digital systems technology, and substitution of faulty throw-away modules. Devices designed to teach digital logic currently are in use at the schools at Dam Neck, Virginia. As in the sonar family, some unmet requirements appear to exist for digital training at the systems level. No generalized training devices presently are available for this purpose.

Surface-to-air fire-control systems are basically analog and digital computing devices. They are modularized, although the modules predate the SHP program. They employ automatic fault-localization subsystems. The training requirements generated by these systems lie essentially in the area of computer technology, but with emphasis on theory and maintenance of electromechanical components. The philosophy of maintenance is substitution of good modules for bad, with no shipboard repair of faulty modules. Standardization programs have not yet made their influence

known in this area. There are no family-specific training devices in use at present; none are indicated for development because the equipment is becoming digital at such a rapid rate. However, there appears to be a requirement for digital systems training at the Class A level.

Underwater fire-control systems are those installed aboard submarines to launch missiles (SUBROC) and torpedoes, and those installed aboard destroyers to launch anti-submarine missiles (ASROC). All existing submarine fire-control systems are special-purpose, analog computing devices. However, all fire-control systems presently being designed and to be designed in future years are basically digital computers. The fire-control solution is developed by means of a computer program consisting of arithmetic processes that operate on input data in real time. Destroyer fire-control systems are both analog and digital, with analog equipment more prevalent at this time. It should be noted that the maintenance responsibility for ASROC fire-control equipment is entrusted to the Sonar Technician (ST) rate; all other systems mentioned are maintained by Fire-Control Technicians (FT).

A generalized underwater fire-control system training device has been proposed and is being considered. If built, it would serve the training needs of existing *analog* systems installed aboard both destroyers and submarines. The conclusion is inescapable, however, that there will never be another analog or another self-contained underwater fire-control system. Thus, training requirements for underwater fire-control systems of the future must emphasize the digital technology area. The desirability of developing a generalized fire-control system trainer for *existing* equipment is an exercise in cost-effectiveness and beyond the scope of the present study.

Within the fire-control area, there appear to be many requirements for devices to train both digital logic and digital systems technology. As mentioned earlier, devices are available now to teach digital logic. The "BI-TRAN SIX" is used in the Fire-Control Class A School at Mare Island to teach basic digital computer technology. However, it is oriented specifically toward computers and is not well adapted to teaching digital systems technology in its more general form.

TORPEDO GUIDANCE SYSTEMS. Modern torpedoes are immensely complex devices incorporating both digital and analog circuitry. A torpedo weapons system includes the torpedo and its associated guidance and control devices, but does not include the underwater fire-control system. A severe training problem exists in the torpedo area, largely as a result of the many different types of torpedoes that have been developed. To complicate the problem, the Mk 48 torpedo recently has been designed, adding an "order-of-magnitude" increase in complexity and training requirements.

Torpedo training is conducted at the Torpedoman's Mate (TM) School at Orlando, Florida. The Mk 37 torpedo is used as a vehicle for Class A training. In addition, a torpedo maintenance trainer designed by Sperry Gyroscope Company is being constructed by the school for its own use.

All torpedoes share the same philosophy of maintenance; the weapon is divided functionally into replaceable sections that are tested externally for proper operation using special-purpose, contractor-provided, test equipment. If a section of the weapon malfunctions, that section is replaced in its entirety. Then, fault isolation and repair to the individual component level is carried out on the bench at a maintenance depot, usually a submarine or destroyer tender.

An important part of Torpedoman's Mate training is teaching the functional organization of torpedoes, including the purpose and operation of each section of the torpedo and its relation to other sections. This particular task is ideally suited to training using a generalized device. The development of a generalized torpedo maintenance trainer specifically is indicated. The design and use characteristics of such a device are described in the section following.

COMMUNICATIONS SYSTEMS. It is important to distinguish between communications equipment and communications systems, a distinction not made definitively until recently. Communications equipment includes transmitters, receivers, teletype terminals, band-shift devices, antenna couplers, antennas, patch panels, encoders and decoders, etc. A communications system is a linked network of communications equipment designed to serve a particular communications requirement. Communications

equipment installed aboard ship can be combined and interconnected to form many different communications systems, depending on the specific need.

The importance of the systems view is shared by procurement and training personnel. The procurement responsibility lies with NAVELEX. Although they currently buy equipment rather than systems, their engineers believe that much can be gained by adopting a systems view. In their opinion, however, it will never be possible to buy communications systems, as such, because many equipments are common to various systems. Training personnel recognize the value of the systems view because there are many shipboard communications maintenance problems that require knowledge of the interface among system components that cannot be gained from a study of the components themselves.

Like many families of electronic devices, communications systems reflect the general trend toward digital technology. However, communications equipment, considered as a total group of devices, does not lend itself readily to digital implementation, largely because of the high-frequency radio energy involved. High-frequency, very high-frequency, and ultra-high-frequency equipment continue to be the standard means of communications among surface ships, and between surface ships and shore installations.

At the present time, no generalized training devices are available in either the communications equipment or communications systems area, although one is currently being designed. However, certain transmitters and receivers are the "workhorses" of the Fleet; they are installed aboard many types of ships in large numbers. To a limited extent, these workhorse equipments might be considered as generalized training devices on the theory that skill and knowledge elements gained from them can be applied widely.

Standardization at the components/equipment level plays an important role because the individual equipments are sufficiently small that wide-spread standardization is feasible. At the present time, NAVELEX is standardizing on certain transmitters and receivers to purposely reduce the variety of available types.

The Naval Schools Command at Treasure Island, California, and Great Lakes, Illinois, have instituted a unique sequence of instruction at the Class A level called "Shipboard Equipme. Indoctrinatio." (SEI). This is a 12-week "systems" package consisting of four weeks of instruction on a single side-band equipment, three weeks of instruction on UHF equipment, three weeks of instruction on telecommunications equipment, and a two-week "systems" course on the interrelations among the equipments listed above.

It is specifically indicated that a communications systems maintenance trainer be developed by NTDC. It is further indicated that each of the components making up the system be a generalized device in itself. NTDC currently is developing a transceiver trainer, Device 8B27, which appears to be an excellent start in the direction recommended. Both the component trainers and the composite systems trainer would find immediate application in at least four schools where maintenance of communications equipment is taught.

NAVIGATION. The family of navigation systems is composed of two distinctly different types of equipment: (1) inertial navigation systems, consisting of a stable platform and associated circuitry, and (2) radio navigation systems, consisting of sensitive receivers and associated digital processing circuitry. Both types of systems exhibit many features of the new technology: digital techniques are widely used; modularized construction is common; maintenance by substitution of good modules for bad is typical; and automatic faultfinding is utilized.

The most common of the inertial systems is the Ship's Inertial Navigation System (SINS). It is installed aboard nuclear submarines and some surface ships. Its output is ship's exact position relative to a set of fixed coordinates. Since its design years ago, the equipment has gone through a series of model changes to continually improve its accuracy and decrease its size. Maintenance of this equipment is the responsibility of the Data Systems Technician (DS) rate.

Radio navigation systems are designed to receive signals either from shore-based transmitters or orbiting satellites, and to compute

own-ship's position from the nature and timing of these signals. Except in the receiver portion of the systems, digital technology is used widely. Modularization with throw-away maintenance is common for all but the analog section of the equipment.

In the navigation systems family, it appears practical and most advantageous to use the actual systems for training, conducted now primarily at the Class C level, since only one or two equipment types are installed at present and are planned. As satellite navigation becomes more common, more types of equipment will undoubtedly appear. However, the new systems will be largely digital and will require no additional training devices.

DATA SYSTEMS. This important family of Naval equipment consists of computers and their associated devices, often called "peripherals." General-purpose display systems, although the maintenance responsibility of the DS rate, more properly belongs in the Command/Control area, to be discussed next.

The AN/USQ-20 and AN/UYK-7 are the two most common computers in use aboard ship. They are identical in many respects: both are manufactured by UNIVAC; both are completely digital and modularized; neither is built to SHP standards; both have automatic test equipment (in the sense that fault localization in computer systems is accomplished by test programs run on a computer).

The UNIVAC Digital Trainer (UDT) is used extensively at the Data Systems Technician School at Mare Island, California. It is important, however, that the UDT is oriented completely toward teaching computer technology. Like the parent computers, it utilizes UNIVAC construction techniques. As long as the Navy continues to buy computer equipment only, or mostly, from UNIVAC, the UDT will likely serve adequately as a computer systems trainer. However, if computers are ordered from other manufacturers, or if computers are built to SHP standards, the UDT trainer will no longer be adequate. No additional training device development is indicated that is intended uniquely for the computer maintenance area.

COMMAND/CONTROL. This family of electronic systems has grown substantially over the years and now assumes mature status, as exemplified by the Naval Tactical Data System (NTDS). This and other such systems consist generally of multiple display stations, central computers, and associated peripheral devices. Inputs to these systems are derived from own-ship's sensors and the sensors of friendly ships, submarines, and aircraft. They include radar, sonar, ECM, and tactical information. Their general purpose is to aid command personnel in decision making by presenting a composite picture of the status of forces and events that exist. Command/Control systems do not typically portray unprocessed data, but rather deal with locations, courses and speeds, dynamic tactics, and probabilities of occurrence.

Command/Control installations typically are very complex, involving substantial gross bulk of electronic equipment. However, there are few items of any single equipment model, seldom more than 20. As such, it would be difficult to justify the development of a training device for this family and none is indicated. It is predicted, however, that several small Command/Control systems will be developed in the future. Therefore, the possibility of *future* requirements for generalized training devices is not ruled out at this time.

TRAINING SITUATION ANALYSES - OVERVIEW

At each Naval school visited, the predominant impression gained was one of change--important and imminent change. Naval school personnel have become aware that newly-designed electronic systems will require many new skills and knowledges for both operation and maintenance, but opinion is divided on the nature of required curriculum change. There seems to be agreement that the change must involve a partial or full conversion to instruction in digital technology, but important questions remain. First, is there any longer a requirement to teach basic electronic circuit theory? Second, should instruction in vacuum-tube technology remain as part of the curriculum? Third, are major revisions required and coming in the basic structure of Naval training?

There is much evidence indicating that the Data Systems Technician rate will increase in importance and in the number of enlisted personnel required as data systems themselves increase in number. There is some evidence that the Sonar Technician rate and the Fire-Control Technician rate could be merged successfully into the data systems area as sonars and fire-control systems become "digitalized." There is speculation on whether the newer modularized systems having automatic test equipment can be maintained at a satisfactory level of performance by unskilled or semi-skilled personnel. In short, the entire atmosphere of Naval enlisted technical training at the present time appears to be one of expectancy for imminent change.

Actual change, however, is far less evident, although definitely in process. Instruction in digital technology has been instituted at a dozen or more schools. Table 2 lists each school offering such instruction, with the identifying course number, type of course, and position within the overall curriculum. With reference to the table, it can be seen that most schools are assigning digital training to the A-2 level of instruction. This is a significant fact because it establishes the requirement at a *general* level; that is, students must be trained in digital techniques *before* proceeding to specific instruction on one of the new systems. In addition, it is highly significant that the courses of instruction for digital technology are virtually identical at each of the schools. Instruction is offered in the theory and operation of basic logic elements and in organizing them to fulfill required data-processing functions. Instruction in digital *systems* technology is now offered only at the Data Systems Technician school, and this instruction is oriented totally toward computers and their associated display systems.

It is the opinion of project personnel that the commonality of digital logic and digital systems training to be offered by the various schools will soon be recognized. At that time, it is predicted that a new concept in Naval training will emerge, that of the "electronicsman," or technician generalist. The basic notion is that members of a single enlisted technician rate can maintain successfully over 90% of Naval ship and shore equipment, primarily because of the increasing similarity and commonality exhibited by digital systems.

TABLE 2. NAVAL SCHOOLS AT WHICH MAJOR TRAINING IN DIGITAL TECHNOLOGY IS OFFERED TO ELECTRONICS RATES

School	Course Identifying Number	Type of Course
U.S. Naval School ET Class A, Service Schools Command, U.S. Naval Training Center, Great Lakes	A-100-0015	Electronics Technician A-2 Training (weeks 11, 12, 13 of 15 week course)
U.S. Naval School FT Class A, Service Schools Command, U.S. Naval Training Center, Great Lakes	A-113-0019	Fire-Control Technician A-2 Training (weeks 11, 12, 13, 14 of 15 week course)
U.S. Naval School ET Class A, Naval Schools Command, Treasure Island	A-100-0014	Electronics Technician A-2 Training (planned for 3 weeks of 14 week course)
U.S. Naval Guided Missiles School FT Dam Neck	A-121-0142	Technician (Polaris, Poseidon, Electronics) A-2 Training (weeks 6-12 of 12 week course)
U.S. Naval School FT Class A, Service Schools Command, Mare Island, Vallejo	A-113-0021	Fire-Control Technician A-2 Training (weeks 11, 12, 13, 14 of 14 week course)
U.S. Naval School DS Class A Service Schools Command, Mare Island, Vallejo	A-150-0025	Data Systems Technician A-1 Training (weeks 1-17 inclusive of 18 week course)
U.S. Naval School DS Class A Service Schools Command, Mare Island, Vallejo	A-150-0026	Data Systems Technician A-2 Training (weeks 1-26 inclusive of 26 week course)
U.S. Naval School (Electronics) Naval Station, Norfolk	A-100-0019	Not rate specific A-2 level - Digital Techniques and Principles (Total course: 6 weeks)

TABLE 2. NAVAL SCHOOLS AT WHICH MAJOR TRAINING IN DIGITAL TECHNOLOGY IS OFFERED TO ELECTRONICS RATED (continued)

School	Course Identifying Number	Type of Course
Naval Air Technical Training Center Naval Air Station Memphis	C-191-2010	Training Deviceman
U.S. Fleet Sonar School Key West, Florida	A-130-0039	Sonar Technician A-2 Training (weeks 13/14 of 14 week course)
Fleet Anti-Submarine Warfare School San Diego	A-130-0040	Sonar Technician A-2 Training (weeks 13/14 of 14 week course)
Service School Command Naval Training Center Orlando, Florida	A-123-0131	Torpedoman's Mates (Advanced Undersea Weapons Circuits)

TRAINING "PIPELINES." The term "pipeline" is used to refer to the succession of schools attended by maintenance technicians between their entry into Naval service and their assignment aboard ship or to a shore installation. Training pipelines are shown in Figures 5 through 9 for five enlisted ratings with responsibility for maintenance of major electronic systems. Several trends can be noted with respect to the figures provided. First, an important distinction is evident between four-year and six year enlistees. Maintenance training generally is offered to only those technicians who will obligate for a six-year period. Their remaining tour of obligated service must be long enough to be productive. Four-year obligors generally are assigned only minor maintenance and/or operator responsibility.

Six-year obligors follow a path beginning with Basic Electricity and Electronics school offered at one of the Naval Training Centers. Then, they are sent to a rate-specific school for advanced general electronic theory. Following this, they are assigned to a Class C course in maintenance of a specific electronic system. Provision is

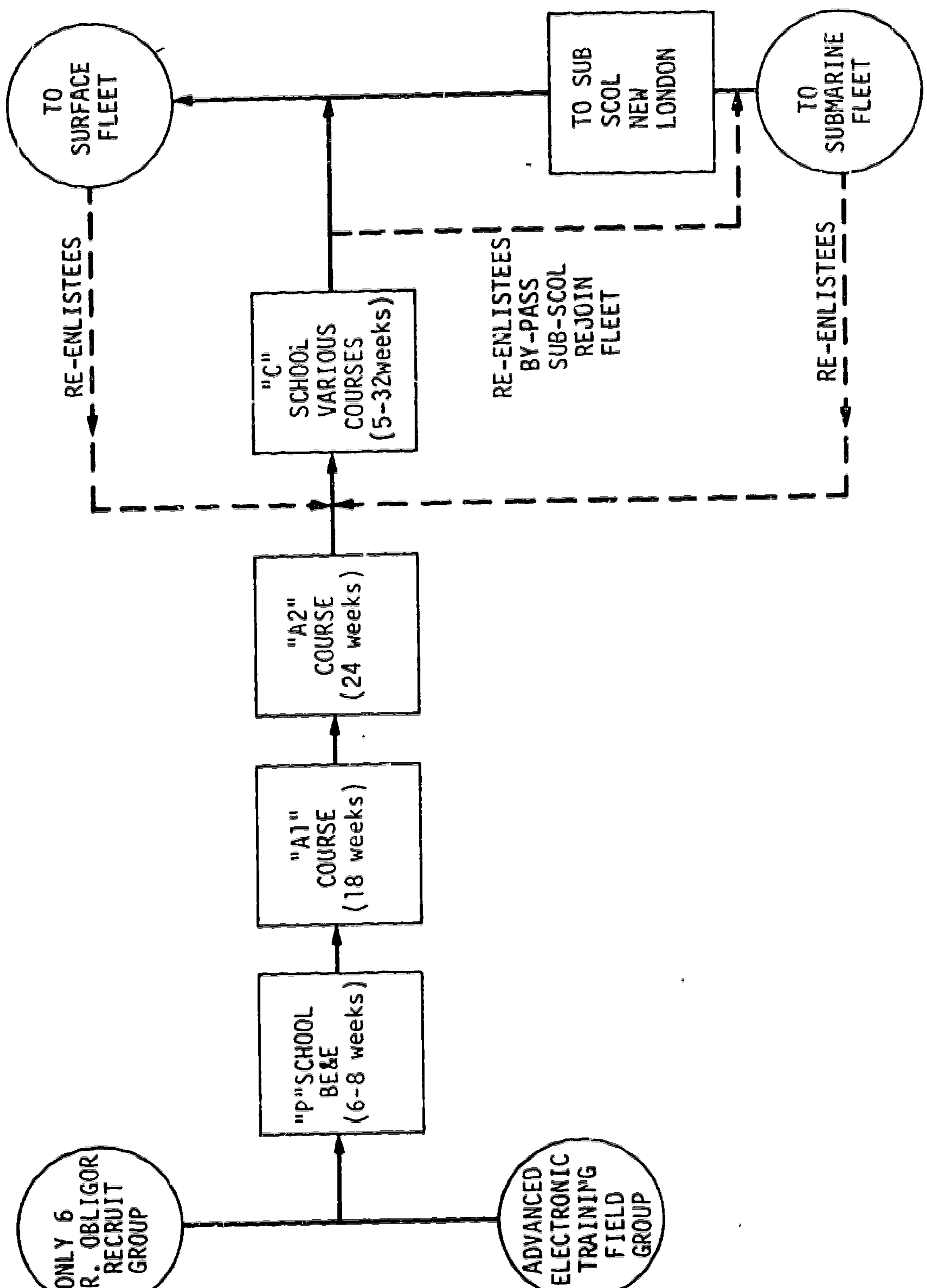

Figure 5. Data Systems Technician Training Pattern

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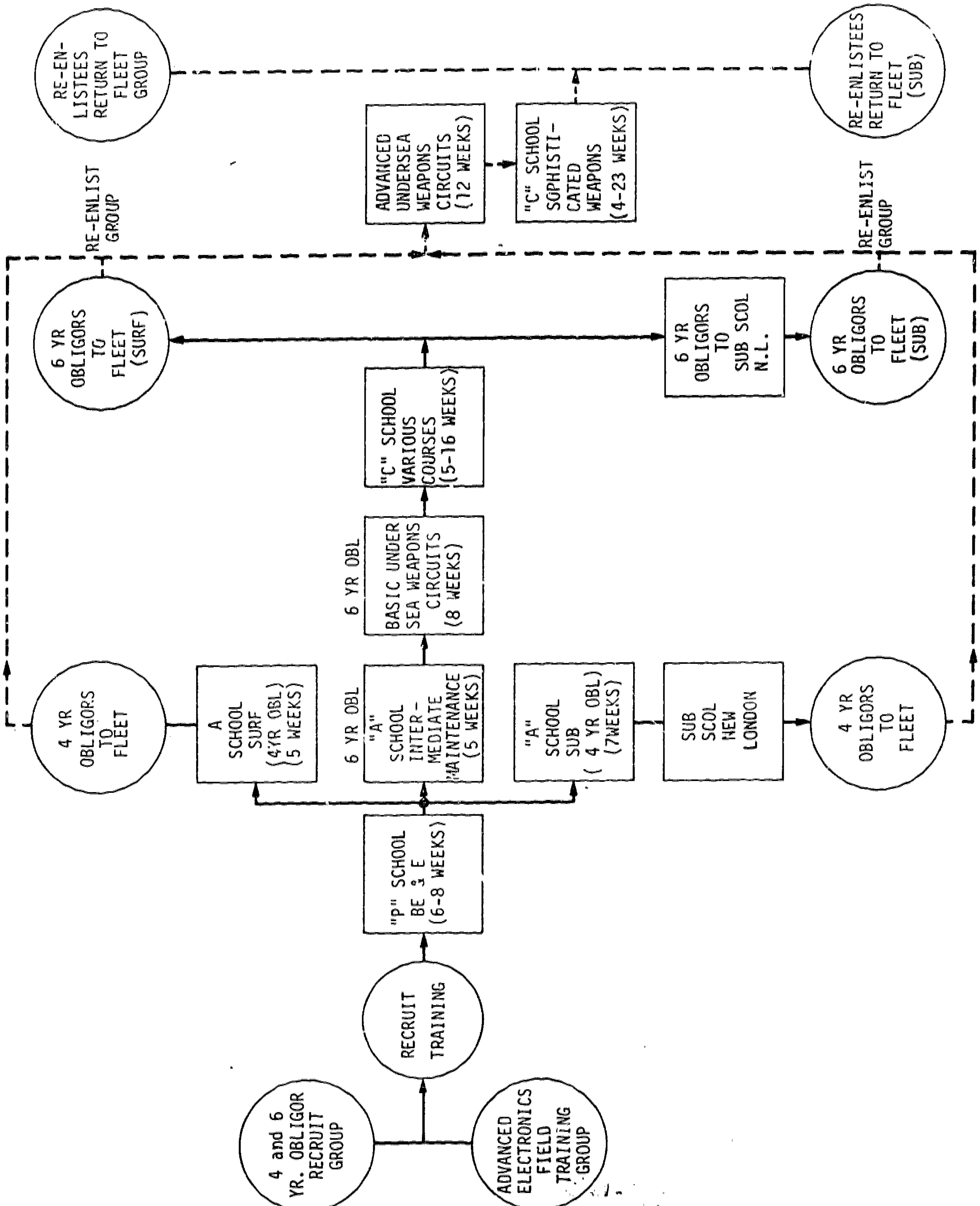

Figure 6. Torpedoman's Mate Training Pattern

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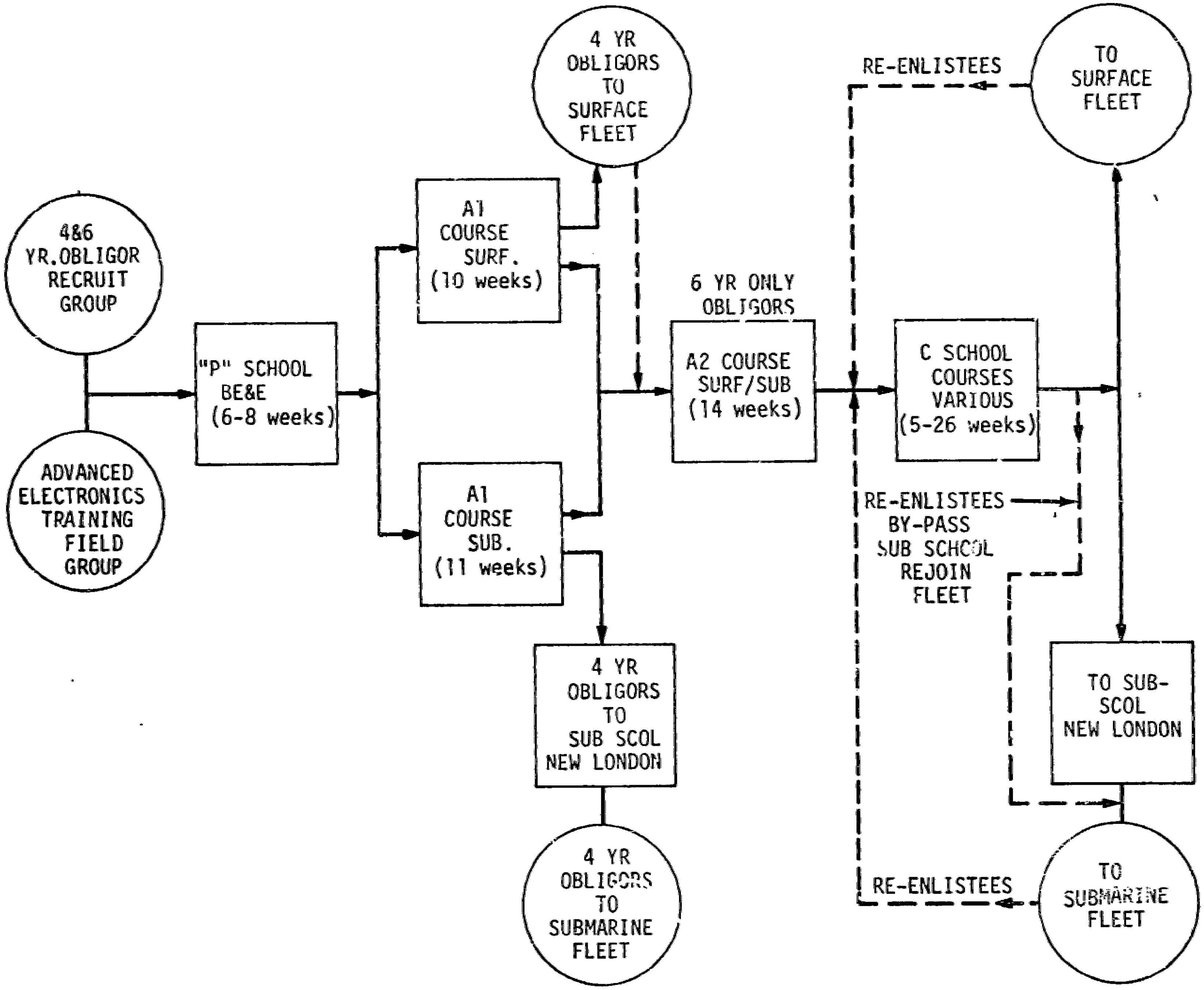

Figure 7. Sonar Technicians Training Pattern

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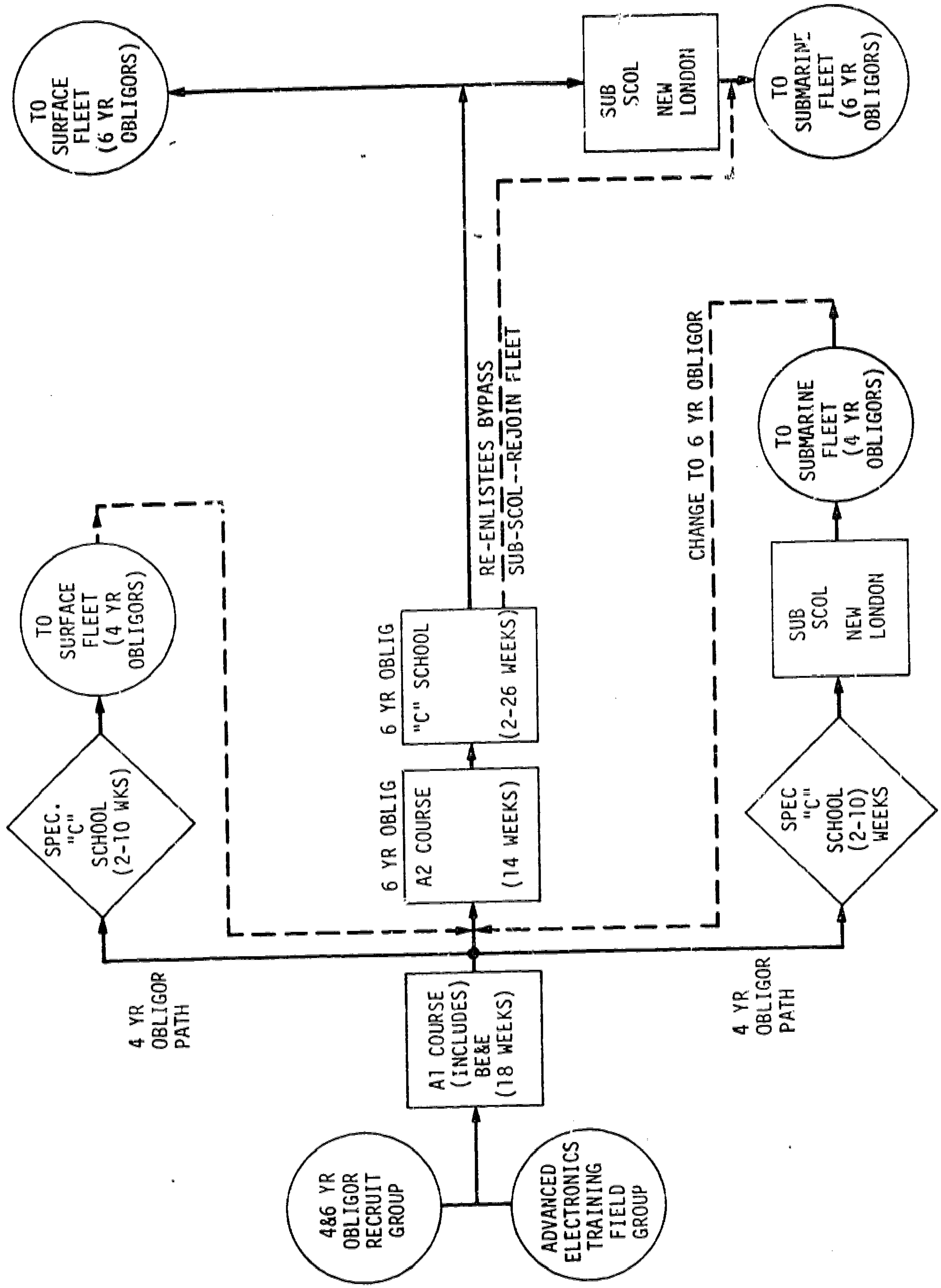

Figure 8. Fire-Control Technicians Training Pattern

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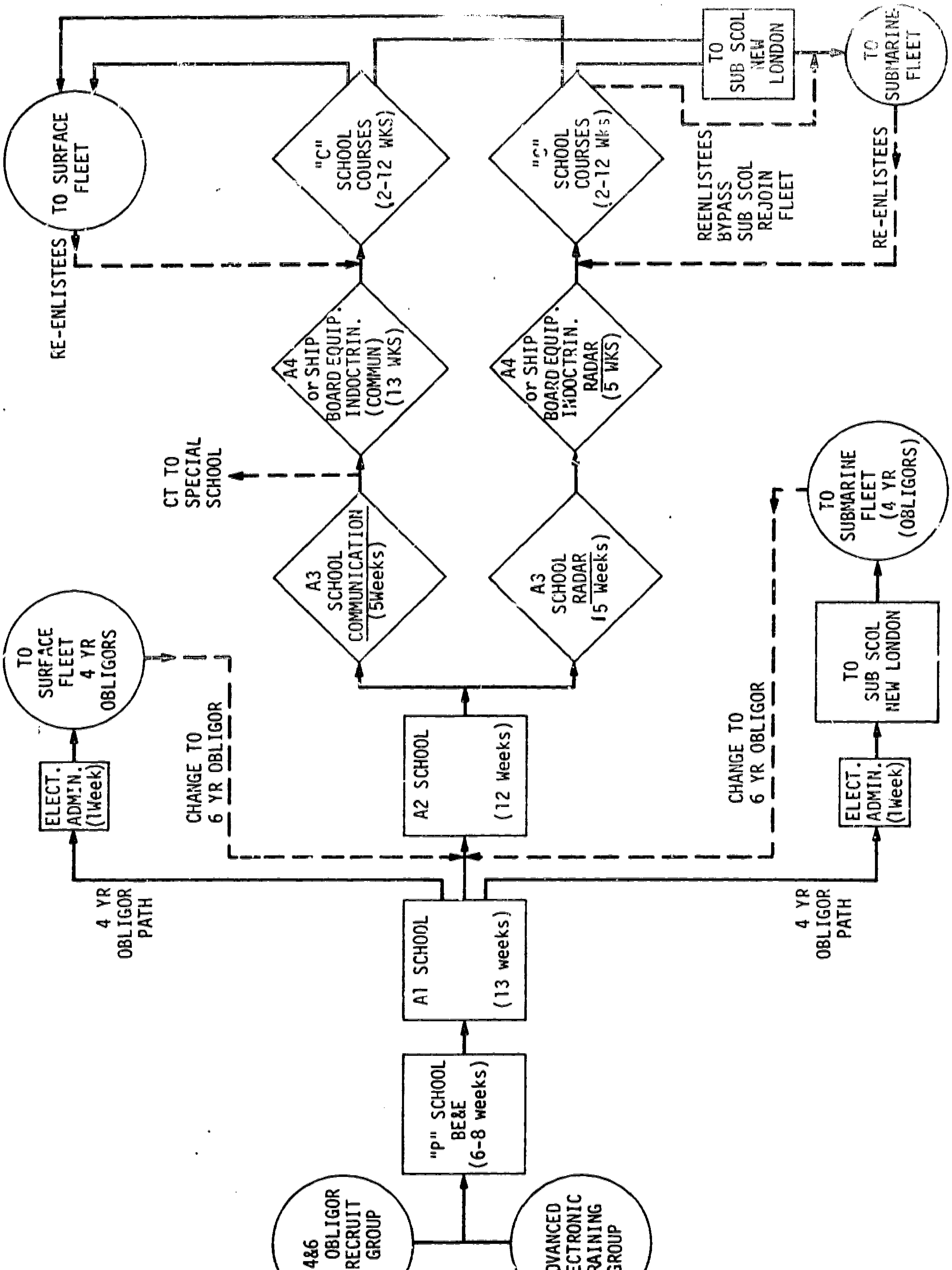

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Figure 9. Electronics Technician Training Pattern

made for four-year obligor personnel to extend two additional years to receive maintenance training. Provision also is made for personnel assigned to Fleet units to return to school for maintenance training at the event of their second enlistment.

Although there are exceptions, technician personnel typically are not exposed to actual electronic systems until they reach the latter phases of Class A training or enter Class C training. In most rates, the general orientation of Class A training and the specific orientation of Class C training creates a situation in which many technicians have difficulty transferring skill and knowledge elements acquired during theoretical training to the actual repair and troubleshooting of electronic systems.

It can be seen from a review of Figures 5 through 9 that typical enlisted technicians receive from six months to over one year of technical training before first assignment. Needless to say, the training process is very expensive, up to $30,000 per man. Clearly, the question of whether modern electronic systems can be maintained by unskilled or semi-skilled personnel is a critical one that must be resolved in the very near future.

ELECTRONIC TECHNICIAN (COMMUNICATIONS) TRAINING. The maintenance of communications equipment is the resonsibility of the ET(N) rate. Training at both the Class A and Class C levels is offered by the Service School Commands at Treasure Island, California, and Great Lakes, Illinois. In addition, selected Class C instruction is offered by the U. S. Naval Electronics School, Norfolk, Virginia.

The communications electronic technician attends BE&E, A-1 and A-2 training in common with the radar electronic technician. Then, the specialities are split; separate A-3 and A-4 courses of instruction are offered. The communications technicians first attend an A-3 course on a typical receiver and a typical transceiver. Then, technicians proceed to an A-4 course of instruction entitled "Shipboard Equipment Indoctrination." This is a 12-week "systems" training package consisting of instruction in single-side-band transmitters and receivers, UHF equipment, telecommunications equipment, and communications systems organization and maintenance.

During the entire 12-week course, actual equipment is used for training. Typically, the equipment is that which is available at the time; most often it is one generation behind the equipment installed aboard ship. The basic idea is that skill and knowledge elements gained using this equipment will transfer to the more modern (and complex) systems. A problem appears to exist in the "systems" portion of this course sequence. The school has assembled a communication system from equipments that were not necessarily meant to operate in conjunction with one another. Interface problems exist among individual units, reducing training effectiveness by distracting attention from the fundamental organization and layout of the system.

A Communications System Maintenance Trainer would find immediate and important use at the three schools described. The system design and use characteristics of such a device are described in detail in the section following.

TORPEDOMAN'S MATE TRAINING. The maintenance of torpedo equipment is the responsibility of the TM rate. Training at both Class A and Class C levels is offered by the Advanced Undersea Weapons School at Orlando, Florida. The training "pipeline" for six-year obligors consists of BE&E school followed by a five-week Class A course in intermediate maintenance, an eight-week course in basic-undersea-weapons-circuits, and one of several Class C courses on a specific torpedo. Four-year obligors attend either a five-week Class A surface equipment course or a seven-week Class A submarine equipment course prior to their first Fleet assignment. Technicians to be assigned to submarines must additionally complete submarine school before being assigned aboard ship. The school also offers a 12-week advanced-undersea-weapons circuits course to second-enlistment personnel. This is a generalized course of instruction that immediately precedes a Class C course in one of the more sophisticated weapons. Up to 23 weeks of Class C training is given to enable technicians to cope with the formidable responsibility of the new MK 48 torpedo.

The Advanced Undersea Weapons School currently is constructing a family of 11 small circuit trainers for use in the advanced-undersea-

weapons-circuits course. Each of these training aids was designed by the Sperry Gyroscope Company to meet a specific instructional need in torpedo maintenance. Personnel at the school feel that, when completed, this series of training aids will adequately meet their needs; they do not recommend further training device development at this time. It should be noted, however, that a generalized torpedo trainer project was started by NTDC some years ago and later abandoned for lack of funds. As such, it is difficult to determine whether school personnel are realistically assessing the need for such a device at the present time or responding to the need as it existed years ago. It is the opinion of project personnel that a generalized torpedo maintenance trainer would serve nicely in at least three different phases of the present curriculum, and that existing training devices do *not* fulfill the need for training in the overall torpedo system concept and for training subsystem organization of modern weapons. A generalized torpedo trainer specifically is recommended; its design and use characteristics are described in detail in the section following.

INSTRUCTIONAL FEATURES APPLICABLE TO GENERALIZED MAINTENANCE TRAINERS. Four techniques were identified as having applicability to generalized *maintenance* training devices: adaptive programming, performance measurement and feedback, guided practice, and perceptual organization.

Adaptive Programming. Adaptive programming is defined as the modification of instruction as a function of the development and progress of individual students; the conditions of practice depend on the degree of success. The notion underlying this principle is that learning is most efficient when practice is neither very easy nor very difficult; thus, adaptive programming can be employed to maintain optimal conditions for learning. In effect, practice conditions and student performance are hooked together in a "closed-loop feedback system." For example, if a student solves a troubleshooting problem above the established standard of speed and accuracy, his next problem will be more difficult. Of course, adaptive programming may be instructor-controlled or machine-controlled. Performance is necessarily measured and assessed in accordance with pre-established standards. It is also possible to have the practice conditions

under control of the student, based on the assumption that students will seek the nature and extent of instruction that best satisfies their own learning needs.

Performance Measurement and Feedback. Performance measurement and feedback include any methods utilized to assess student progress and to inform the student of his progress. Knowledge-of-results is beneficial in any serial learning task, including, of course, troubleshooting. The availability of feedback information requires real-time performance measurement. It requires, in effect, a step-by-step tracking of student behavior, in which the various correct behaviors are recognized, and in which deviations from these behaviors are noted. As long as the student progresses with correct action-goal sequences, he is permitted to proceed without interference; however, if he strays from the correct sequences, he is notified of the error. It is beneficial to allow the student to request information on the status of the equipment and the progress he has made toward solving a corrective maintenance problem. For example, it is helpful for him to learn which possible malfunctions he may already have eliminated, or which sequences of tests he may already have conducted. Conceivably, he could enter descriptions of the possible malfunctions suspected and obtain an assessment whether any of these have already been eliminated by the tests he has completed. In addition, it is likely desirable to have a record of the student's performance history available to him on demand, including: number and type of malfunctions correctly identified, amount of time taken, number of front panel tests initiated, number of replacements, number of times progress was reviewed, and number of times the student started back from the beginning.

Guided Practice. Guided practice refers to equipment features that permit the student to experience correct behavior prior to his ability to exhibit that same behavior. The inclusion of this feature requires real-time performance measurement, which, in turn, requires a model of successful performance against which to track the student's progress. There are several possible ways to provide guidance to the student. In troubleshooting, for example, alternative action-goal sequences might

be suggested. Or, additional instructional materials could be provided. In short, a continuous measurement is made of the student's deviation from a correct model of operation, and guidance is provided when error tolerances are exceeded. For example, a student may enter a command indicating that he wishes to review his progress. The computer may reply by asking him to identify the malfunction that he suspects. The student is then told whether he has enough information to isolate that malfunction and whether or not it is a good possibility. He may also be given a list of other reasonable possibilities that have been overlooked.

Perceptual Organization. Perceptual organization includes those features which provide the student with insights that assist him in understanding underlying principles or patterns. The most promising technique is known as "backwards troubleshooting." Most troubleshooting practice proceeds from the unknown to the isolation of the malfunction. Seldom is there an opportunity for the student to interject a selected malfunction and to see the symptoms and cues that it generates. If the student is curious about the effect of a particular type of malfunction, he can insert this malfunction via the computer, and then observe the symptom pattern that results. He can be given knowledge-of-results for each reading at each test point. This approach seems an effective way to enhance the student's perceptual organization in troubleshooting. Furthermore, it seems a quick way to teach a student about the effects of important malfunctions, particularly those with high probabilities of occurrence.

Provision is made for the use of these techniques in the Digital Systems Trainer, to be described in detail in the section following.

SECTION V

CONCLUSION AND RECOMMENDED TRAINER CHARACTERISTICS

This section of the report contains a related sequence of conclusions on the impact of digital technology on training device design, on the validity of the generalized training device concept for digital equipment, and on the predicted changes in the structure of Naval training that will result from new equipment design. Three generalized training devices then are recommended for detailed conceptual and engineering development. The proposed design of each of these devices is conveyed using a system block diagram and accompanying descriptive material.

CONCLUSIONS

WE ARE IN A PERIOD OF RAPID CHANGE IN THE DESIGN AND CONSTRUCTION OF NAVAL ELECTRONIC SYSTEMS. Many, if not most, systems now being designed and installed in the Fleet use digital techniques. The maintenance and operating procedures required by the new systems are different in kind and in extent from those required by the older analog equipment. Major new requirements are being created for training in both digital logic and digital systems technology. It would appear that a major training device development effort is required to adequately meet the training requirement created by the new systems.

IT IS IMPORTANT TO FORECAST TRAINING DEVICE REQUIREMENTS. In a period of rapid change, training device characteristics must be based on timely and accurate forecasts of maintenance and operational requirements that will prevail during the "use" period of the life-cycle of the training device. If requirements for training devices are based on existing needs, they will not adequately serve the requirements of the newer systems.

THE COMMONALITY IS INCREASING AMONG INDIVIDUAL EQUIPMENTS THAT ARE MEMBERS OF THE SAME FAMILY OF ELECTRONIC SYSTEMS AND ALSO AMONG EQUIPMENTS THAT ARE MEMBERS OF DIFFERENT FAMILIES. The increase in commonality is generated by the swing to digital technology and by the incorporation of many advanced electronic features that increase the similarity among all electronic systems.

THE MAINTENANCE REQUIREMENTS CREATED BY THE VARIOUS DIGITAL SYSTEMS ARE HIGHLY SIMILAR TO ONE ANOTHER. Computer systems and digital sensor systems share more common elements as sensor systems gradually are converted to digital technology. Identifiable trends in the design of electronic systems of all types tend to support the conclusion that the commonality among all systems will continue to increase in the future.

THE GENERALIZED MAINTENANCE TRAINING DEVICE CONCEPT IS MORE VALID WITH THE NEWER DIGITAL SYSTEMS THAN IT WAS WITH THE OLDER ANALOG SYSTEMS. As many as 100 individual circuit elements and sub-units commonly were found among analog systems that constituted members of a family. In contrast, only about 20 circuit elements and sub-units commonly are found in digital computer and digital sensor equipments.

IT IS POSSIBLE TO INCLUDE MOST, IF NOT ALL, REPRESENTATIVE CIRCUIT ELEMENTS IN A GENERALIZED DIGITAL SYSTEMS TRAINING DEVICE. The relatively low number of circuit elements shared by digital equipment makes it possible to think in terms of a single training device intended to serve digital electronic systems in general. Circuit elements are *identical* that are commonly found in digital systems having vastly different operational objectives.

STANDARDIZATION, PARTICULARLY AS REPRESENTED BY THE STANDARD HARDWARE PROGRAM, WILL HAVE A MAJOR IMPACT ON SYSTEM DESIGN AND TRAINING DEVICE DESIGN. The Navy's standardization efforts are beginning to pay off. The diversity of individual elements of electronic equipment is being reduced. Standardizing on a group of pre-designed modules will force a greater similarity in maintenance techniques as time progresses.

IMPORTANT CHANGES ARE PREDICTED IN THE ORGANIZATION OF NAVAL SCHOOLS AND IN THE STRUCTURE OF NAVAL RATINGS WITH ELECTRONIC MAINTENANCE RESPONSIBILITY. There is evidence that members of the Data Systems rate can more adequately maintain digital sonar, radar, and fire-control equipment than can members of the rates trained specifically for that duty. Of course, this is a function of the similarity between computer systems and digital sensor systems.

A REQUIREMENT IS BEING GENERATED FOR A "SUPER TECHNICIAN." Malfunctions arising at a system level in digital equipment will create skill requirements for technicians whose overall knowledge exceeds that represented by today's technician. However, the vastly improved reliability of electronic systems, the inclusion of automatic fault finding systems, and the simplified maintenance techniques of digital systems combine to reduce the required skill level for large numbers of technical personnel.

THE IMPACT ON FUTURE TRAINING DEVICES OF NEW DEVELOPMENTS IN ELECTRONICS APPLIES TO BOTH GENERALIZED AND SYSTEM-SPECIFIC TRAINING DEVICES. Design trends such as standardization, modularization, solid-state circuitry, general-purpose displays, and the like, will influence the design of electronic systems in general, including the training devices intended to serve those systems. In fact, standardization at the components/ equipment level already is required for all training device development.

GENERALIZED TRAINING DEVICE DEVELOPMENT IS INDICATED AT PRESENT IN THREE CIRCUMSTANCES. First, it is indicated for those systems that are not inherently suited to digital implementation. Second, it is indicated for systems utilizing packaging techniques that match nicely with the advantages of the generalized training device approach. Third, it is indicated, and most importantly, for training devices designed to serve digital electronic systems and computers.

RECOMMENDED TRAINER CHARACTERISTICS

Three training devices specifically are recommended for detailed conceptual and engineering development. Two of these are "within-family" trainers: a communications systems maintenance trainer, and a generalized torpedo maintenance trainer. The remaining training device, the digital systems trainer, is an "across-family" device; it is intended to serve at a variety of Naval schools offering instruction to several Naval rates with maintenance responsibility for digital equipment.

DIGITAL SYSTEMS TRAINER. The training device design concept is conveyed in a sequence of three block diagrams, Figures 10, 11 and 12. The device is shown in increasing order of complexity, from major functional sections, through functional units, to functional sub-units. Reference to these block diagrams will assist the reader in interpreting the general comments that follow.

Overview. The Digital Systems Trainer is designed for use both as an operator and a maintenance trainer, but with greater emphasis on maintenance training. It is designed to serve the training needs of both computer systems and digital sensor systems. When used for maintenance training, it is a self-contained training device. It functions as an operator trainer when used with a source of analog signals from a signal simulator, or with real signals recorded on tape. These signals are entered, converted to digital format, processed in accordance with pre-wired or controlled processing techniques, and displayed to the operator, a sequence typical of digital sensor systems. Signals from external digital sensor sources similarly can be stored, processed, and displayed.

The device can function as a programming trainer when used with a paper tape reader or other source of programmed material. Used in this fashion, the student trainee writes a computer program in any of a variety of programming languages, then enters his program into the device (using any of the digital peripheral devices connected to the "Input Digital Interface" channel). The external program then controls all operational sequences of the training device.

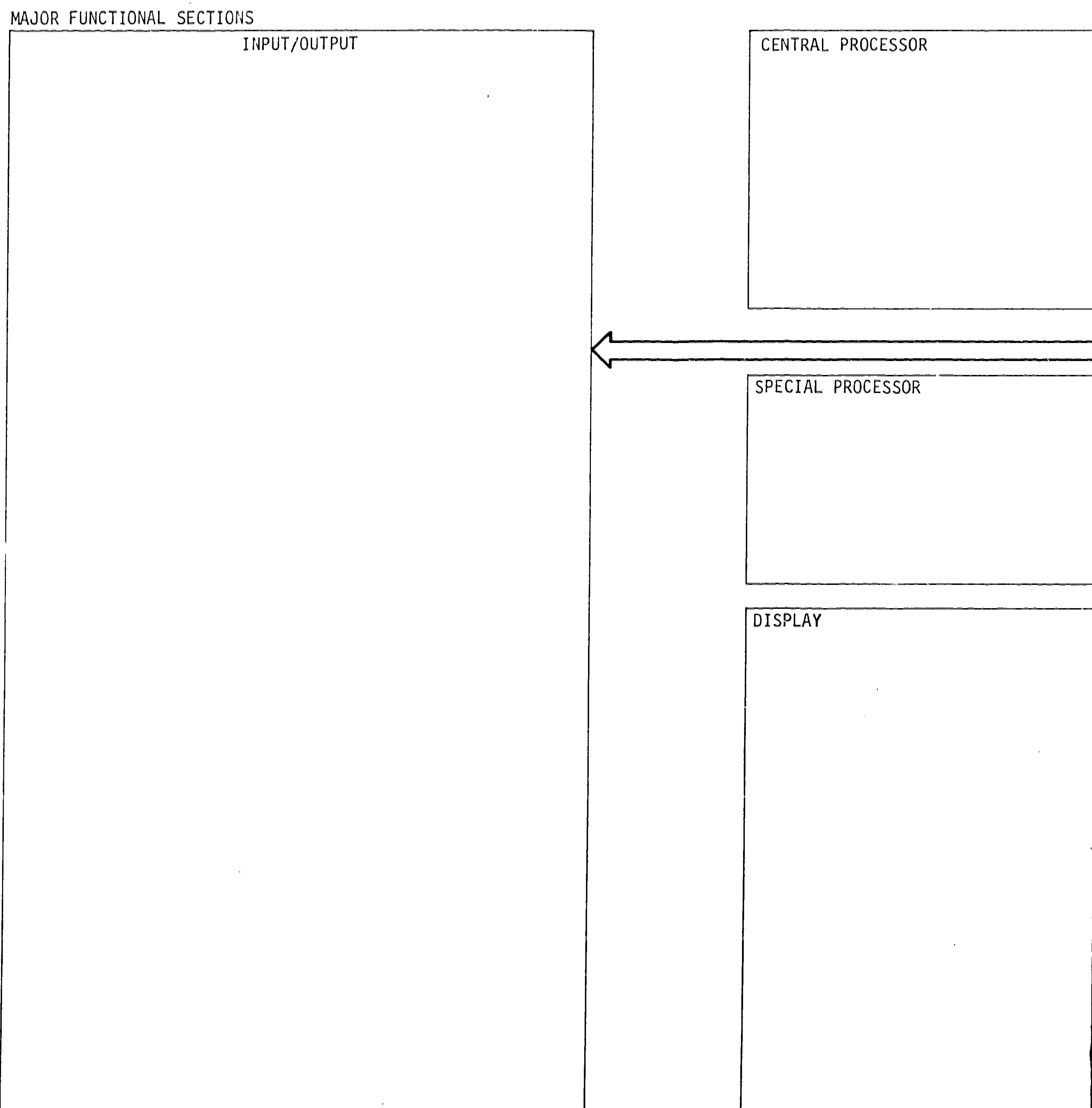


Figure 10. The Dig

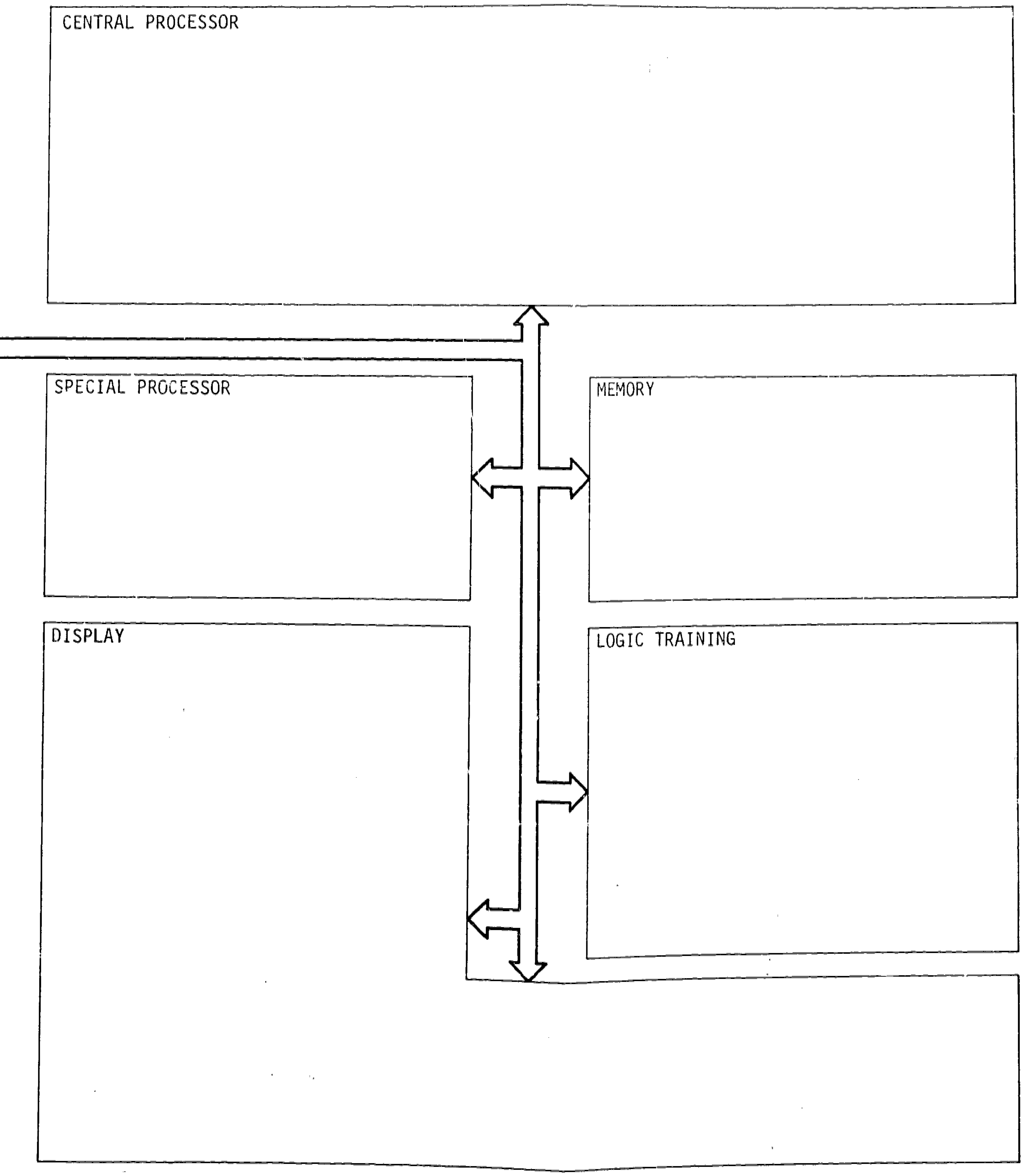


Figure 10. The Digital Systems Trainer - Major Functional Sections

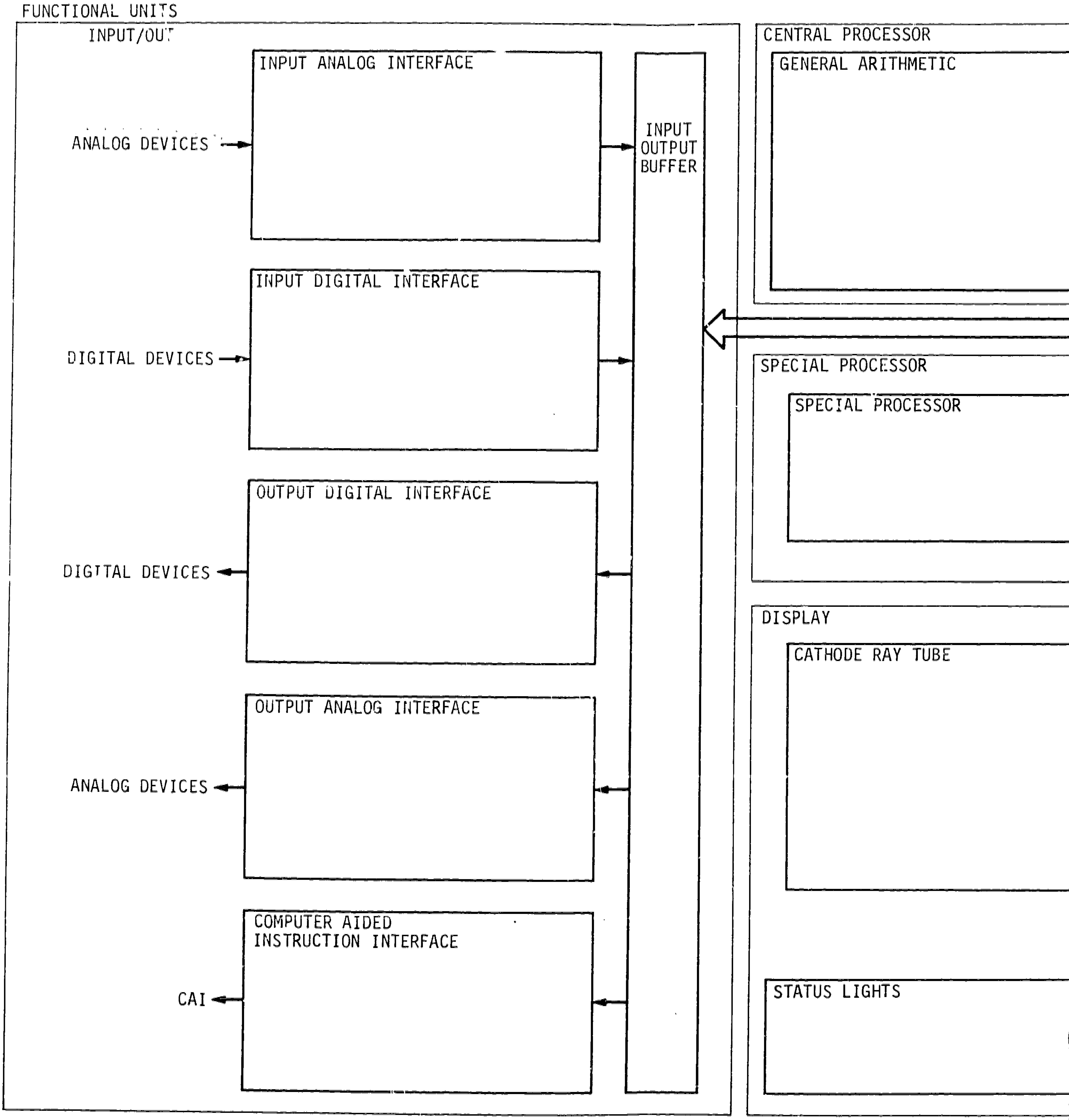


Figure 11. The

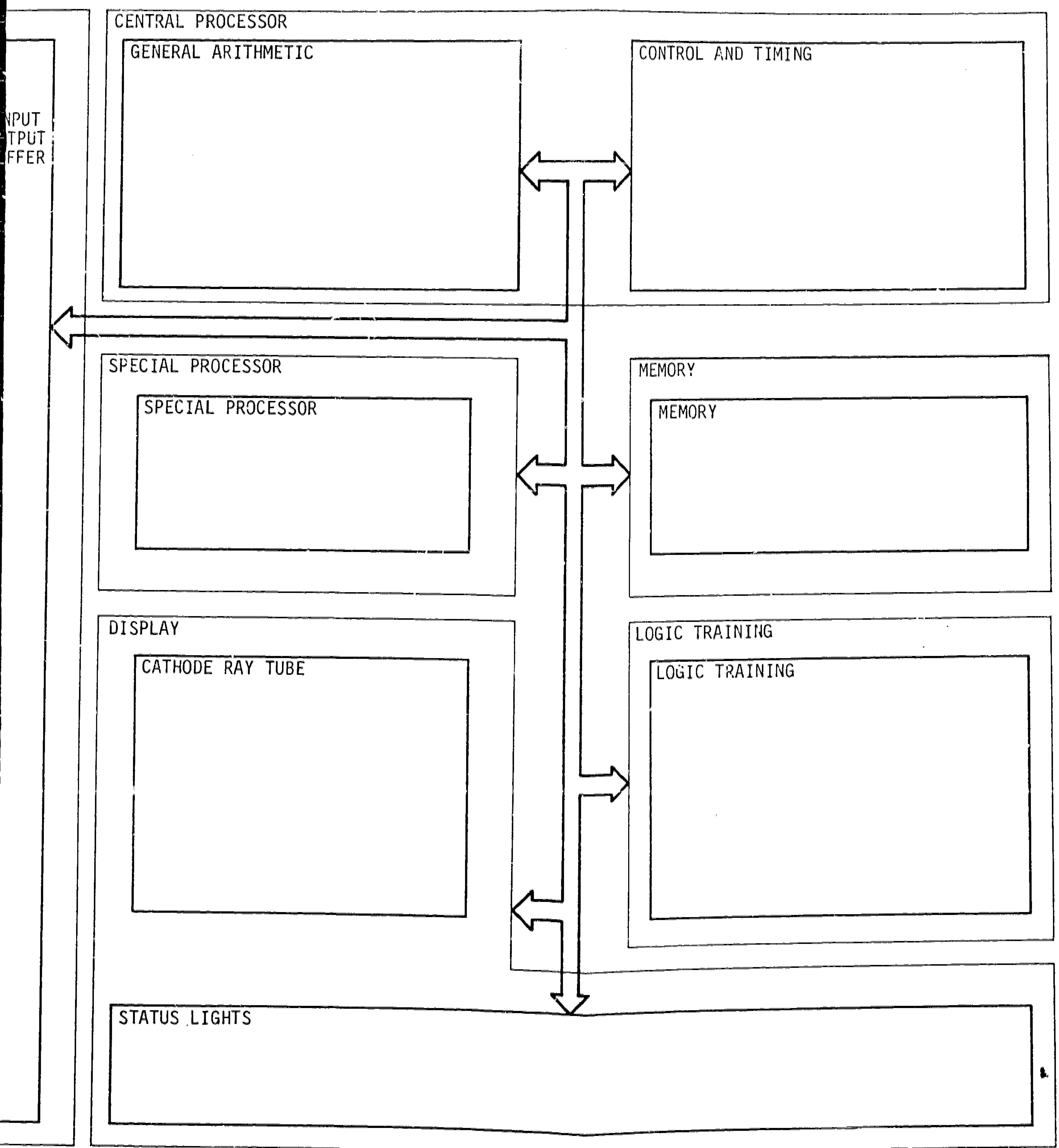


Figure 1. The Digital Systems Trainer - Functional Unit Level

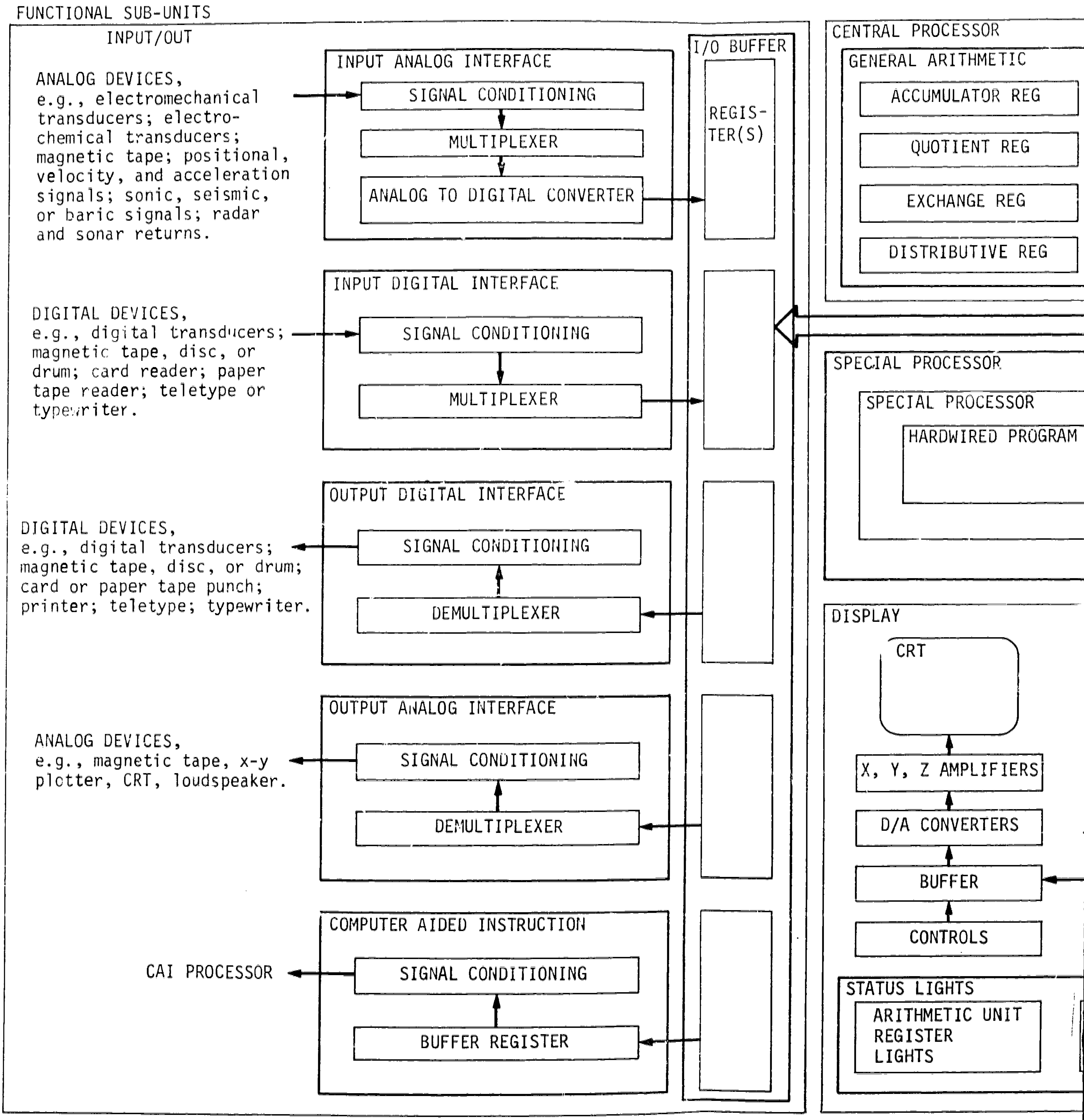

FUNCTIONAL SUB-UNITS
INPUT/OUT
ANALOG DEVICES, e.g., electromechanical transducers; electrochemical transducers; magnetic tape; positional, velocity, and acceleration signals; sonic, seismic, or baric signals; radar and sonar returns.
INPUT ANALOG INTERFACE
SIGNAL CONDITIONING
MULTIPLEXER
ANALOG TO DIGITAL CONVERTER
DIGITAL DEVICES, e.g., digital transducers; magnetic tape, disc, or drum; card reader; paper tape reader; teletype or typewriter.
INPUT DIGITAL INTERFACE
SIGNAL CONDITIONING
MULTIPLEXER
DIGITAL DEVICES, e.g., digital transducers; magnetic tape, disc, or drum; card or paper tape punch; printer; teletype; typewriter.
OUTPUT DIGITAL INTERFACE
SIGNAL CONDITIONING
DEMULTIPLEXER
ANALOG DEVICES, e.g., magnetic tape, x-y plotter, CRT, loudspeaker.
OUTPUT ANALOG INTERFACE
SIGNAL CONDITIONING
DEMULTIPLEXER
CAI PROCESSOR
COMPUTER AIDED INSTRUCTION
SIGNAL CONDITIONING
BUFFER REGISTER
I/O BUFFER
REGISTER(S)
CENTRAL PROCESSOR
GENERAL ARITHMETIC
ACCUMULATOR REG
QUOTIENT REG
EXCHANGE REG
DISTRIBUTIVE REG
SPECIAL PROCESSOR
SPECIAL PROCESSOR
HARDWIRED PROGRAM
DISPLAY
CRT
X, Y, Z AMPLIFIERS
D/A CONVERTERS
BUFFER
CONTROLS
STATUS LIGHTS
ARITHMETIC UNIT REGISTER LIGHTS

Figure 12.

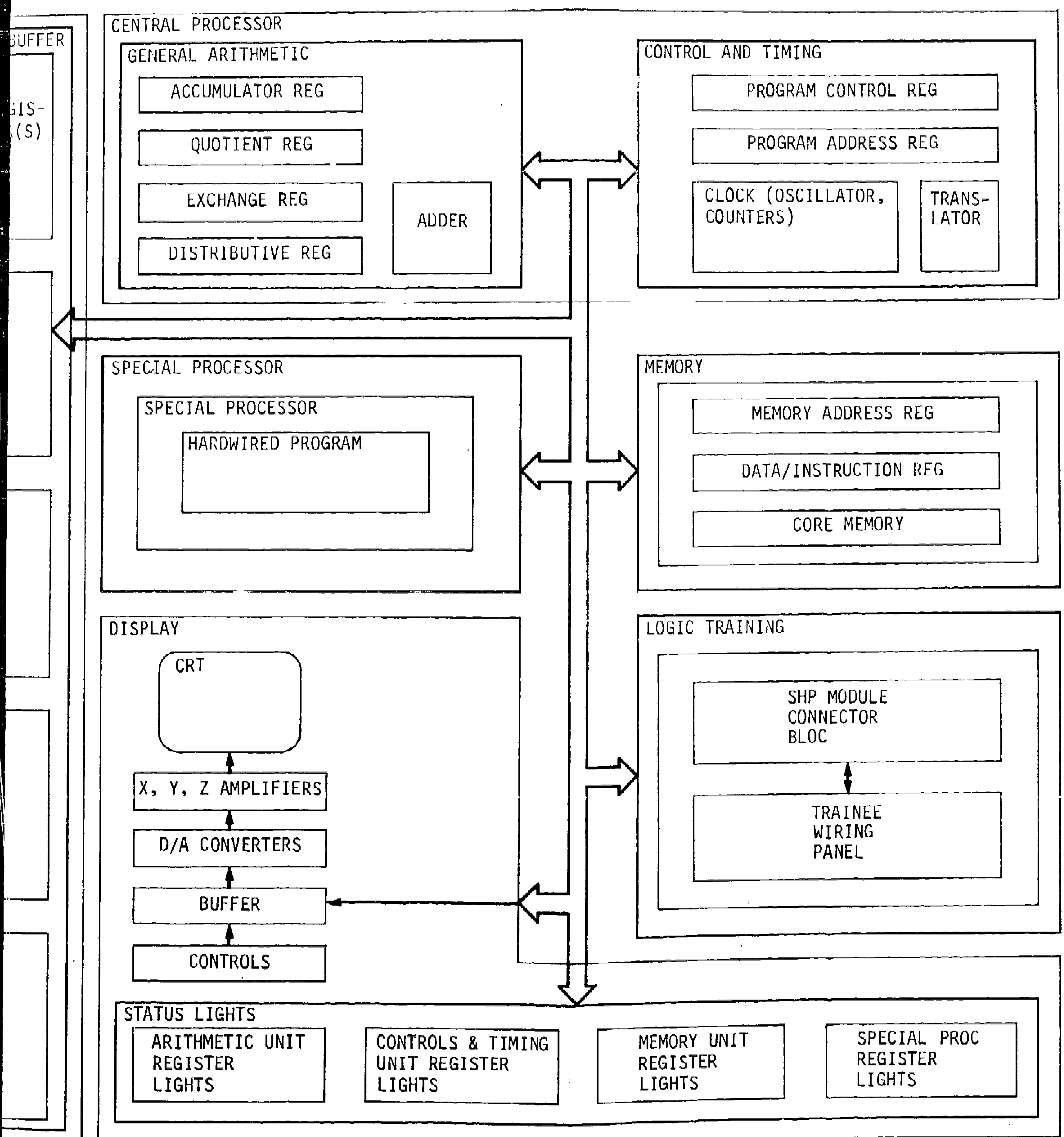


Figure 12. The Digital Systems Trainer - Functional Sub-Unit Level

The various operations are sequenced through the device at a rate selected by the student using the "Control and Timing" unit. With this feature, the operator/trainee can see immediately the accuracy and success of the program he has written. He can also cause the program to be displayed, stored for further use, or subjected to selected arithmetic operations.

Used as a digital logic trainer, the device can accommodate one or more trainees. The trainer contains a "Logic Training" unit that can be replicated to provide a number of independent student stations, although shown, for convenience, as a single unit in the block diagrams. Only one station at a time can interconnect to the main portion of the trainer and operate "on-line." However, students using several "Logic Training" units can simultaneously assemble any configuration of digital logic modules to provide any type of desired arithmetic or processing operation. Then, these modules can be "exercised" with the training device one at a time. Thus, a group training feature for digital logic is provided. The "Logic Training" unit is designed to perform all the functions of existing digital logic trainers; however, the trainer has the additional important feature of allowing trainees to observe the result of using the assembled logic in the overall system operation.

The Digital Systems Trainer can be used in "hard-wired" fashion with a computer-assisted-instructional processor, typically a digital computer on which training programs are stored. The training device provides the vehicle by which malfunctions can be entered directly from the training computer. The trainer then exhibits the exact symptom pattern that would result from a similar failure in a computer or digital sensor system. The device can be used with any newly-developed, computer-assisted-instructional technique provided a compatible language has been adopted. It is simply necessary to program the training technique desired on the master computer, to program and enter the training routine desired for the Digital Systems Trainer and run the two programs in conjunction with one another. If desired, several Digital Systems Trainers could be made slave to one CAI processor to provide group maintenance training in basic digital logic and digital systems technology.

Design Characteristics. The Digital Systems Trainer provides for the simulation of most functions of digital sensor systems and computer systems. It contains equipment components and features representing a wide variety of digital systems, and illustrates processing techniques common to both computer and digital sensor systems: analog-to-digital conversion, multiplexing, register storage, memory storage, single-phase and multiphase clocks, data translation, shift registration, accumulation, word addition, selection and recycling, and several forms of signal conditioning, to name a few. The input/output characteristics of each of the important digital circuits can be illustrated and its function demonstrated to the student. Training can be conducted effectively in localization and repair techniques appropriate to each circuit type.

It is specifically intended that the trainer and each of its subunits be built of Standard Hardware Program modules. Skill and knowledge elements uniquely related to SHP modules can be developed directly and exercised using the trainer, and these skills will transfer uniformly to a wide variety of modularized systems. Provision is made, using the "SHP module connector block" of the "logic training" unit, to accommodate new module types, such as those containing LSI circuitry or representing technologies that may develop in future years.

With reference to Figure 12, it can be seen that the device has been designed to receive any of a variety of signals from associated analog devices, in general, from any device that converts energy existing in a medium to electrical signals. These signals are changed from analog to digital format and stored in a buffer register for processing. The trainer also can accept signals from any of a variety of digital input devices, generally signals that exist already in word-compatible digital format. A program stored on punched paper tape, magnetic tape, disc, drum, or teletype reader can be used to control the training device through the digital input channel. Then, the data can be subjected to any of a series of arithmetic operations, signal transforms, or processing routines. These instructions are taken from either the central or special processors, or can be specially programmed at the logic training unit. The resulting signals, thus transformed, can be displayed in real time to the operator,

stored in the CRT display buffer for later display in accelerated time, or outputed to an external device in either digital or analog format. The results of each separate arithmetic operation can be stored in memory to be later recalled for combining with additional incoming information.

The device contains a series of status lights that show the disposition of information everywhere in the training device in real time. The contents are displayed of the arithmetic unit, the control and timing units, the memory, and the special processor.

The "Control and Timing" unit provides and controls three modes of operation: "manual," "sequence," and "run." In the "manual" mode, the operator sequences data through the training device one step at a time by pressing a pushbutton. The location and status of digital words are continuously displayed to the operator so that he can observe the progression of information through the system. In the "sequence" mode, the data sequences through the training device at a rate of one step per second, controlled by a 1 Hz. clock. In the "run" mode, the data sequences through the device at any arbitrary high speed, perhaps 10 KHz.

Any of three types of arithmetic operations can be performed: (1) the central processor can perform any stored arithmetic function on the data stored or provided to it, (2) the special processor can provide any "hard-wired" transformation on the data stored or provided to it, and (3) the "Logic Training" unit can be used to assemble (from SHP modules) any desired arithmetic operation or processing technique. The output can then be used to transform stored data or that provided to it.

Intended Application. The Digital Systems Trainer will, of course, find immediate use at Naval schools teaching digital logic. The device can be adapted readily and easily to existing curricula for digital logic training and is recommended for use in that application. A complete list of those schools is shown as Table 2.

The device would find immediate use as a systems trainer at the Data Systems Technician School at Mare Island, California, the only Naval maintenance training school at which digital systems training presently is offered. Of course, the device does not exist at present, and, as

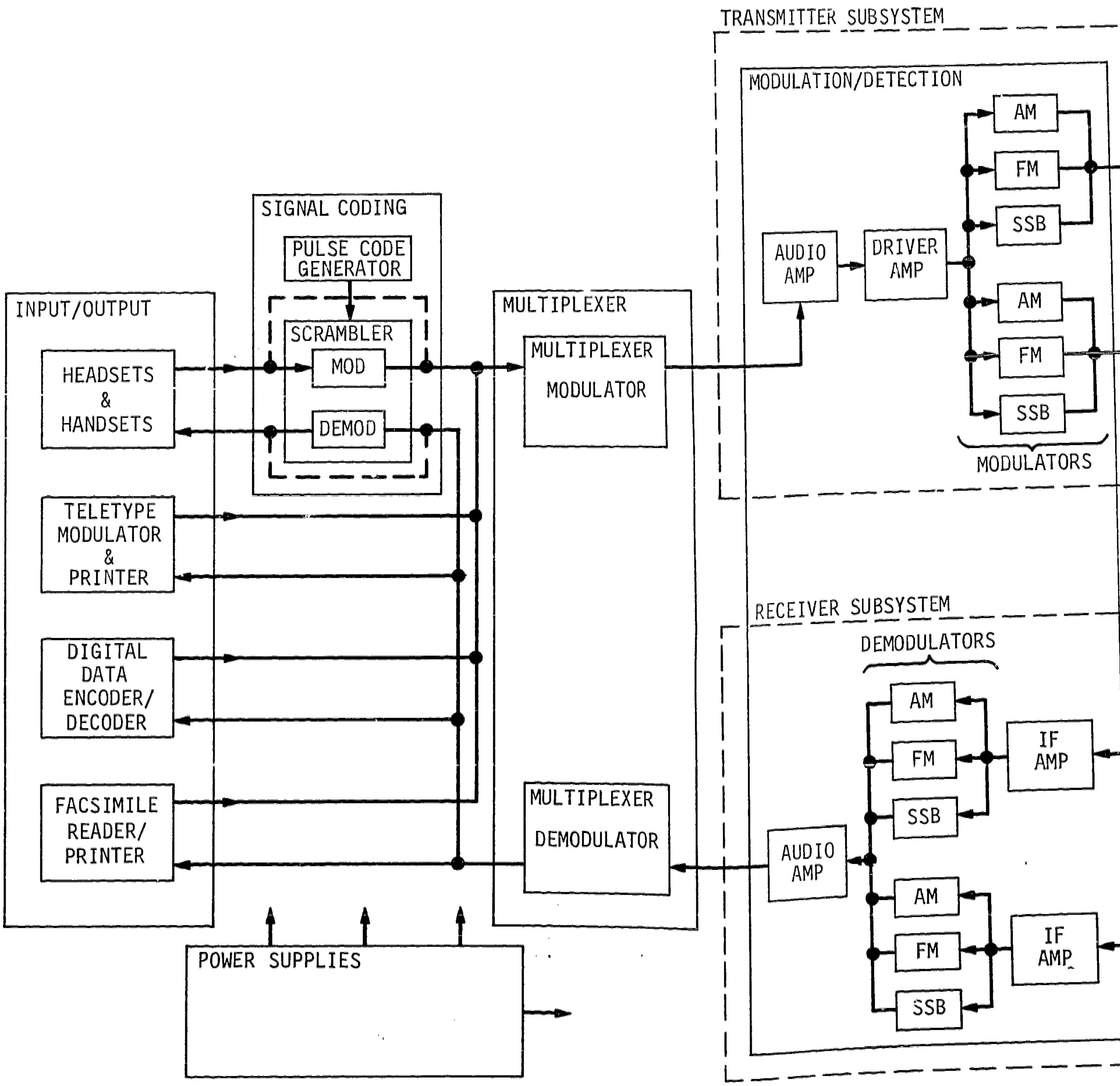
such, discussion of its relation to existing curricula implies that the curricula will not change in the near future. Quite to the contrary, it is expected that the curricula of all Naval schools will change dramatically in the future to include instruction in both digital logic and digital systems technology. The availability of the training device will allow new curricula to be structured to take advantage of the capability that it provides. It is predicted that the device would find immediate and important uses in *every* new digital logic and digital systems technology curricula. It is considered to be the most important single maintenance training device, and the most highly generalized, developed thus far to our knowledge.

COMMUNICATION SYSTEMS TRAINER. The training device design concept is conveyed as a system block diagram, Figure 13, developed to the "functional units" level. Reference to the diagram will assist the reader in interpreting the general comments that follow.

Purpose and Operation. The Communication Systems Maintenance Trainer was designed for use in teaching maintenance skills associated with shipboard communication systems. It is intended for use in ET(N) training at the Electronic Technician (Communications) schools at Treasure Island, Great Lakes, and Norfolk. Its features were selected to fit directly into the existing curriculum.

The device is intended, generally, for use in teaching the basic operation and the interface requirements of communication equipment that is assembled into communication systems. However, each of the subsystems in the maintenance trainer is, in itself, a generalized training device. For example, the "Transmitter Subsystem" section of the device is a generalized transmitter trainer; the "Receiver Subsystem" section of the device is a generalized receiver trainer.

The device incorporates a series of input/output devices of the type typically found in the radio "shack" of every Naval destroyer, headsets, teletypes, data links, and facsimiles. It also includes sections for signal coding, multiplexing and demultiplexing, transmission and reception, transmit/receive switching, multi-coupling, and antenna loading.


TRANSMITTER SUBSYSTEM
MODULATION/DETECTION
AM
FM
SSB
AUDIO AMP
DRIVER AMP
AM
FM
SSB
MODULATORS
SIGNAL CODING
PULSE CODE GENERATOR
SCRAMBLER
MOD
DEMOD
INPUT/OUTPUT
HEADSETS & HANDSETS
TELETYPE MODULATOR & PRINTER
DIGITAL DATA ENCODER/ DECODER
FACSIMILE READER/ PRINTER
MULTIPLEXER
MULTIPLEXER MODULATOR
MULTIPLEXER DEMODULATOR
RECEIVER SUBSYSTEM
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AM
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POWER SUPPLIES

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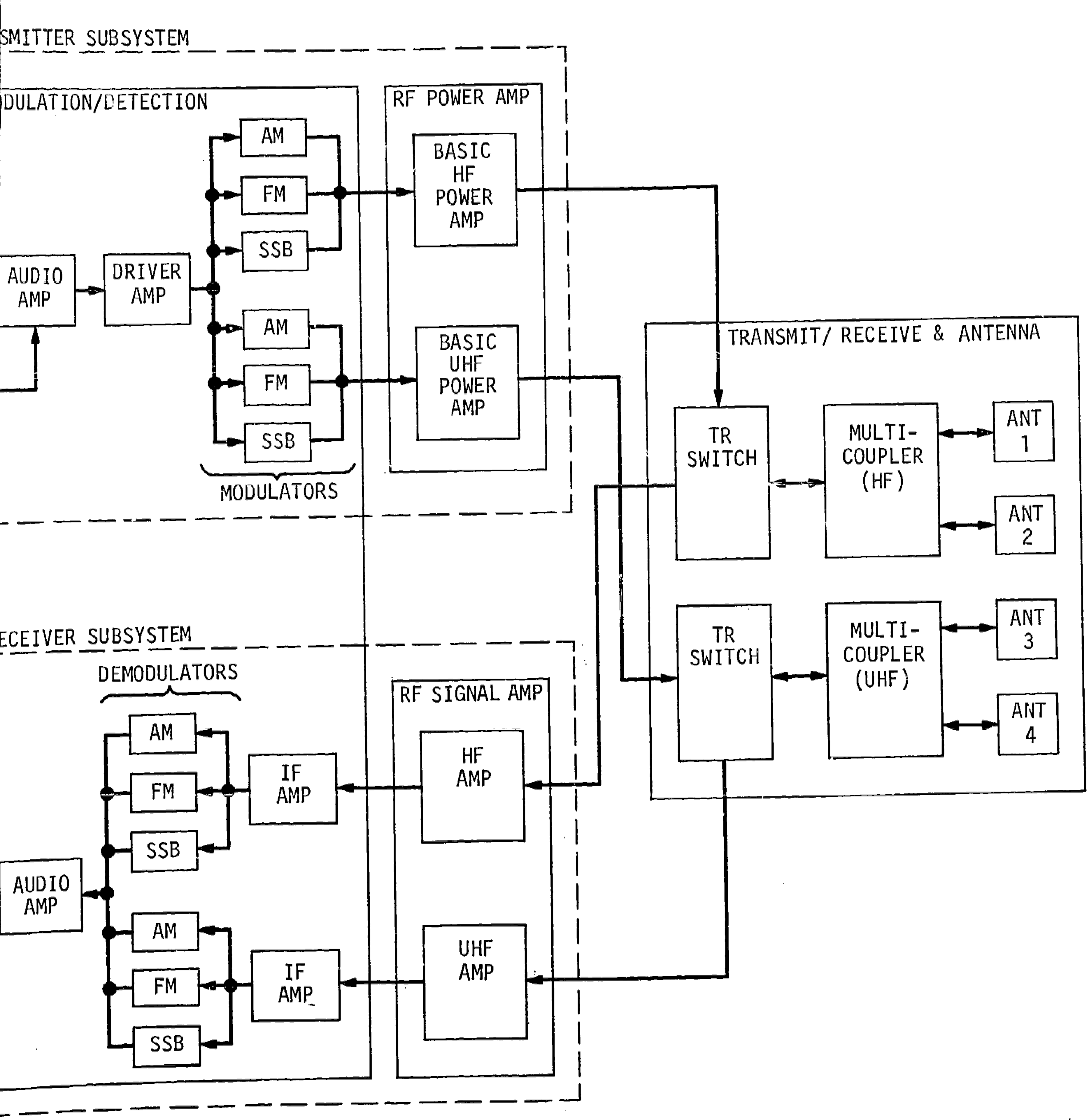

Figure 13. The Communications Systems Maintenance Trainer

As such, it can be used to illustrate any of the basic equipment functions and interfaces, and to exercise localization and repair techniques typical of basic communication equipment.

The device is intended for construction in sections, so that each section by itself can be used during basic equipment training. Then, in the latter, or "systems," portion of communications training, the separate sections (with which the trainee presumably is familiar) are assembled into communications systems that can be operated and interconnected realistically.

The training device is designed to complement, rather than to substitute for, the actual communications equipment now used for training. The training device would be used first to convey the overall system concept and the organization of subsystems within the system. Then, practice problems would be given in troubleshooting and repair using the typical circuitry provided in the training device. Finally, the students would be exposed immediately to the counterpart section of the actual equipment, so that the transfer of organizational knowledge would be immediate. Once the functional organization and operation of specific circuits were understood, trainees could quickly grasp differences between the generalized circuitry and the counterpart circuitry in the actual equipment. Rather than spend full time on actual equipment as is practiced today, perhaps only 20 percent time would be spent on actual equipment, providing the highest possible training effectiveness. This technique would prevent specific skill and knowledge elements associated with obsolete equipment from being learned. It would also allow new models of actual equipment to be substituted for existing models without disruption of curriculum or teaching methodology.

Intended Application. The Communication Systems Trainer is intended for use during the final 17 weeks of the 48-week, Class A, ET(N) training sequence. The generalized transmitter and receiver subsections of the equipment are intended for use during the first five weeks of this 17-week period, providing training in receiver, transmitter, and transceiver technology. As previously mentioned, a generalized transceiver

training device presently is being procured by NTDC, although design of the device has not yet begun. It is suggested that this development could nicely be incorporated into the Communication Systems Trainer, to be used specifically during the third, fourth, and fifth week of the 17-week training sequence.

Naval communication systems are not inherently suited to implementation using digital technology. As such, the basic nature of these systems is not expected to undergo major change during the next few years. At most, digital signal processing devices will be added and digital data encoding and decoding devices will become more prominent. Pulse modulation techniques may also become more commonplace. However, the basic format of transmitting and receiving equipment is expected to remain fairly constant. Therefore, the recommended training device likely will find application to existing curricula both now and in future years.

GENERALIZED TORPEDO MAINTENANCE TRAINER. A block diagram of the recommended training device shown as Figure 14. Reference to this block diagram will assist the reader in interpreting the general comments that follow.

Purpose and Operation. The Generalized Torpedo Maintenance Trainer is intended specifically for use at the Advanced Undersea Weapons School at Orlando, Florida. Its primary purpose is to convey the organization and function of major subsystems that comprise modern undersea weapons, with emphasis on the interfacing of sub-units within the overall weapon.

The Generalized Torpedo Maintenance Trainer concept is not new, nor is it a new device. Some years ago, NTDC initiated a program to develop the device and later abandoned the program due to lack of funds. The design concept was developed by NTDC personnel and later carried to the "proposal solicitation" stage before being cancelled. The block diagram shown as Figure 14 was developed, in essence, by NTDC personnel some years ago. However, it is still relevant today; the organization of modern weapons has not changed dramatically. The change has been in the implementation of the various units, primarily using modern technology.

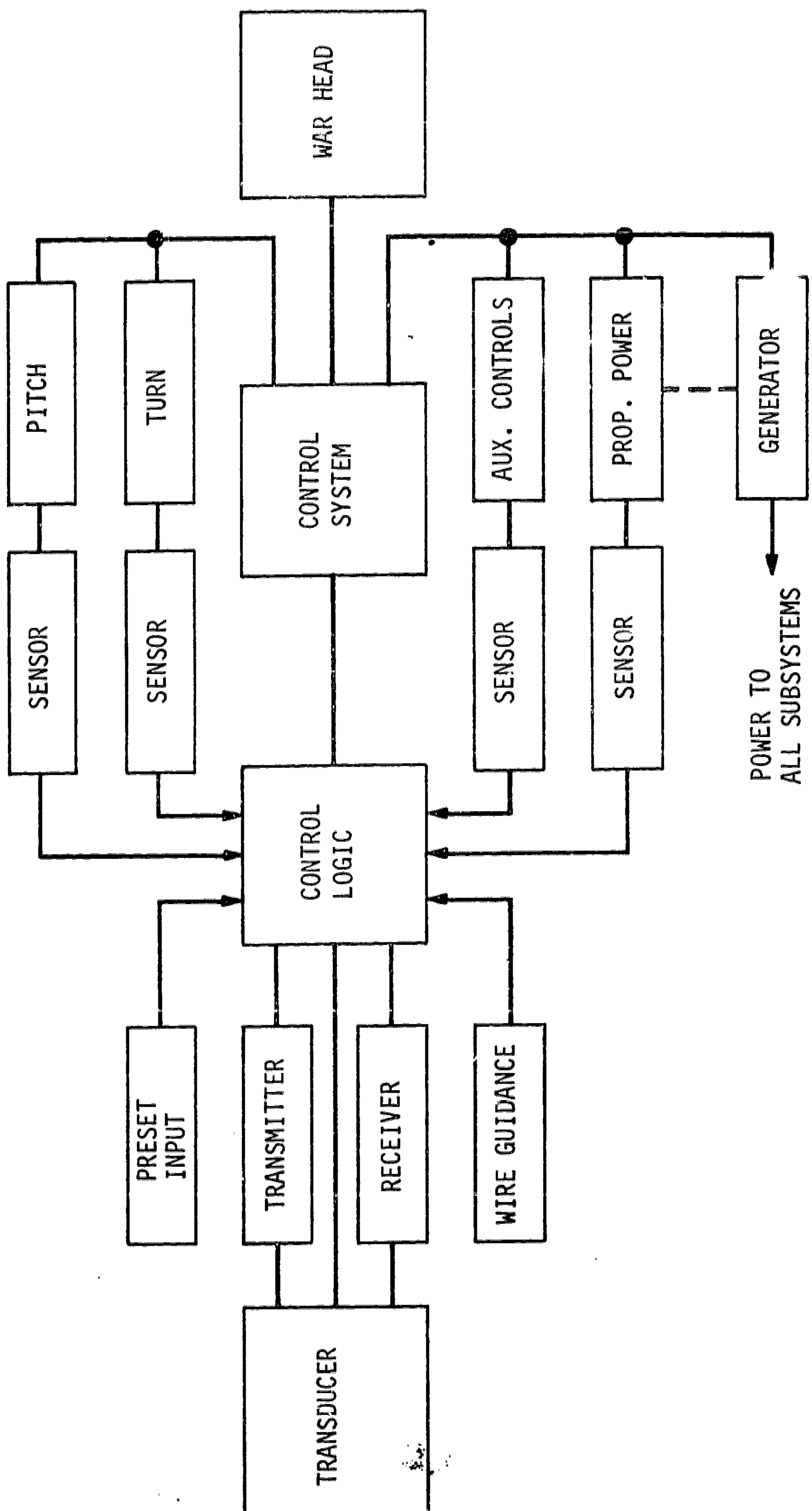

Figure 14. The Generalized Torpedo Maintenance Trainer.

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It is contended that the concept of the Generalized Torpedo Maintenance Trainer is valid today and that the device would provide enhanced training at the Orlando school. However, personnel at the school are familiar with the previous project; they refer to the device as the "paper torpedo." They do not feel that a generalized trainer *as they envision it* is required at present.

The Mk 37 torpedo is used as a training vehicle in the Class A training sequence at Orlando. In addition, a sequence of 13 small "training devices" is being assembled by the school for use in the advanced-underwater-weapons-circuits course. These training devices were designed by Sperry Gyroscope Company as the end product of a maintenance task analysis conducted several years ago. The use of a sequence of small devices such as these is based upon a "part-to-whole" training concept; the underlying contention is that the whole is exactly equal to, and no more than, the sum of the parts. In contrast, the recommended maintenance trainer is based on a "whole-to-part" training methodology; the overall system concept is conveyed to the student *before* the function and operation of the components. And, the whole is much more than the sum of the parts. As such, the recommended training device would complement nicely the sequence of devices being built at present. It may also be possible to use existing functional diagrams and components from the 13 trainers in constructing a generalized "system" trainer.

Intended Application. The Generalized Torpedo Maintenance Trainer is intended specifically for use during the 7th and 8th weeks of the Basic Undersea Weapons training course and during the 9th, 10th and 11th weeks of Advanced Undersea Weapons Circuits training. It is contended that the recommended device would find immediate and important use in these phases of the torpedo training curriculum.

APPENDIX A
FEATURES OF STANDARD HARDWARE MODULES

This appendix consists of a sequence of photographs that together illustrate the important design features of SHP modules. The photographs and the accompanying text have been included for three reasons: (1) it is highly probable that the SHP Program will have a major impact on both generalized and equipment-specific training devices of the future, (2) it is recommended in the body of this report that a digital systems trainer be built and that it conform to SHP standards, and (3) it is believed that SHP modules are representative of modern, modular packaging techniques that will be widely utilized in future training device development.

As described in the text, SHP modules have been used to implement many Naval electronic systems; the photographs illustrate the level of sophistication already achieved. In addition, Naval Program Managers now are required to utilize SHP techniques for ship and shore equipment unless convincing reasons exist for not doing so. It is expected, therefore, that the use of SHP modules will increase significantly in future years.

The basic module is approximately three inches wide, two inches high, and one-fourth inch thick. It consists of a mounting fin, plug-in connectors, guide pins, plastic sideguides, component mounting board, and component parts. Provision has been made for the basic module to expand in span and in thickness. Provision also has been made to accommodate power-handling components and to combine modules into plug-in blocks to accomplish electrical design objectives requiring more than a single module. The modules can be mounted in "card-cages," pull-out drawers, or vertical equipment racks. With little additional design effort, SHP modules can be adapted to any existing packaging technique.

One of the most important features of SHP modules is that they are not "technology limited"; the components mounted on SHP modules can be discrete (capacitors, resistors, inductors, transistors), integrated

circuits, "flat-packs," "dual-in-line packs," medium-scale integrated chips, or large-scale integrated chips. As the technology advances, no doubt there will be new forms of components developed. Standardization on a particular modular format does not restrict technological advance but merely standardizes the input-output characteristics of the module.

More complete information on the SHP Program can be obtained from NAVWEPS OD-30355, a four-volume series describing all details of the SHP Program, or in NAVELEX 0101-051, a Program Manager's guide for the SHP Program.

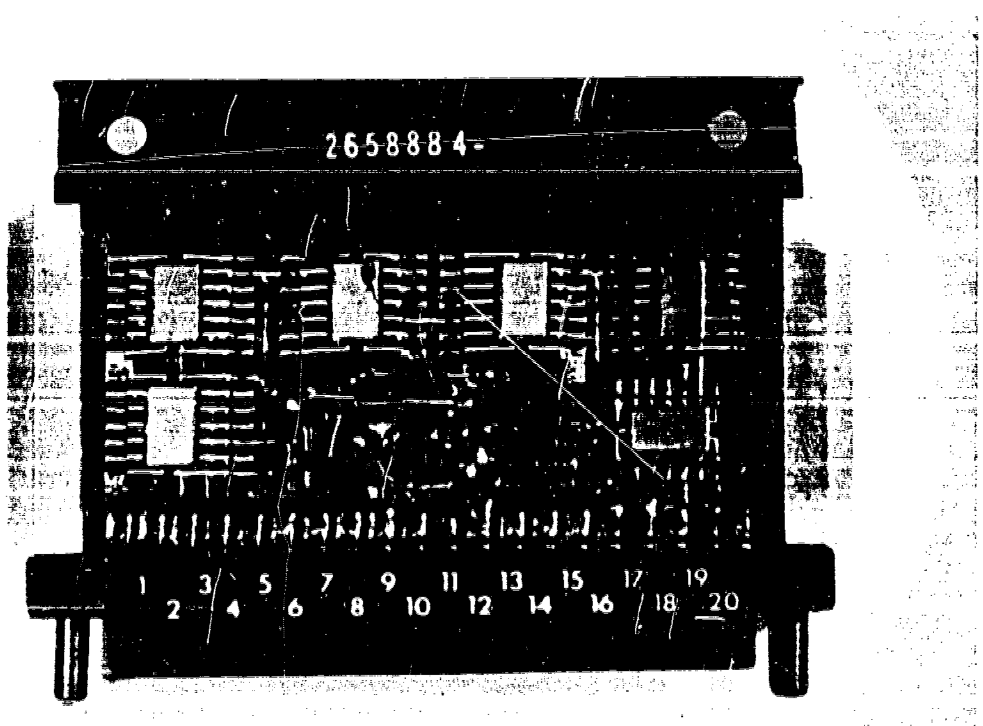

Figure 15. Basic Ship Module

The components mounted on this module are microelectronic "flat-packs" and discrete components (resistors). The mounting fin is the black metal section. Plug-in connectors are recessed under the board numbered 1 to 20.

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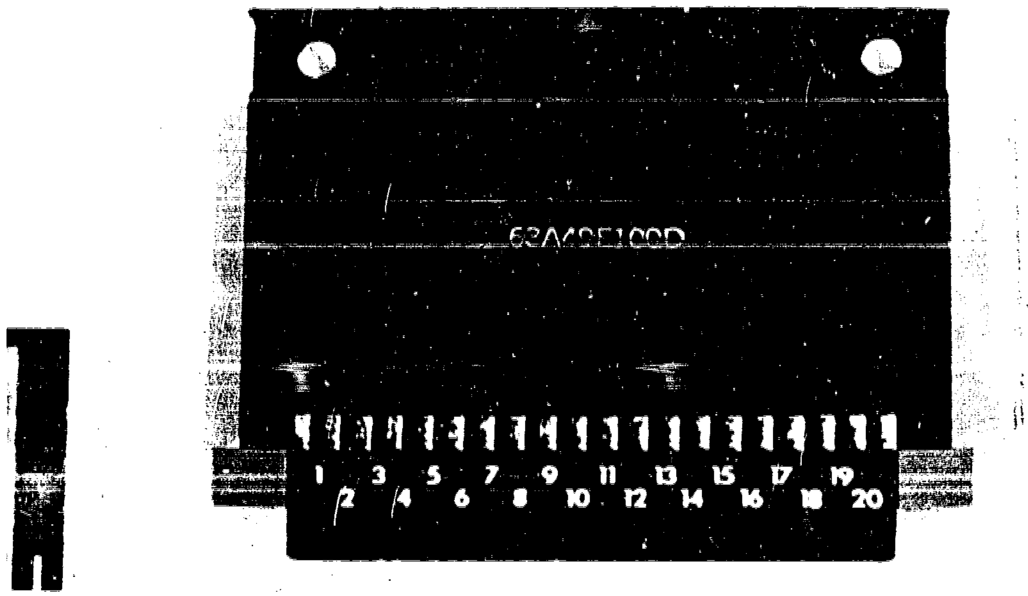

Figure 16. **Basic Module Components**

The black cooling fin has two holes at the top for easy removal. The module is iuentified by a decal attached to the top of the mounting fin. The plastic sideguides can easily be seen.

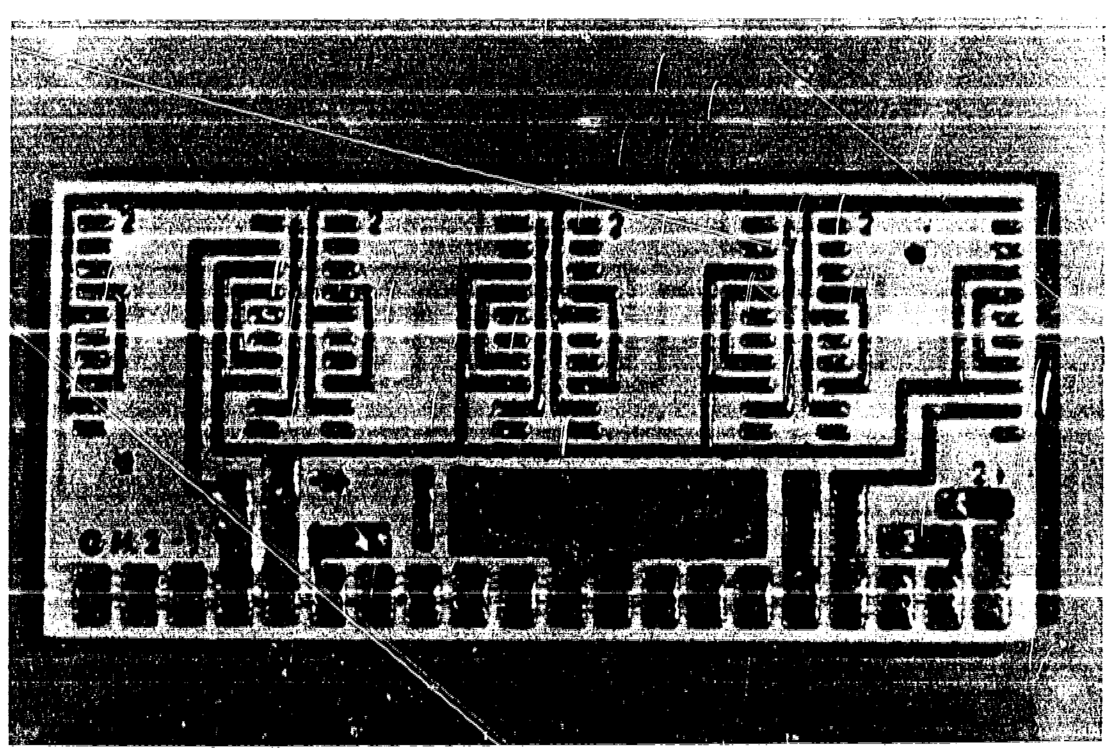

Figure 17. **Component Mounting Board**

The component mounting board is glued to the cooling fin. Several types of mounting boards have been developed; the one shown above is the deposited solder type.

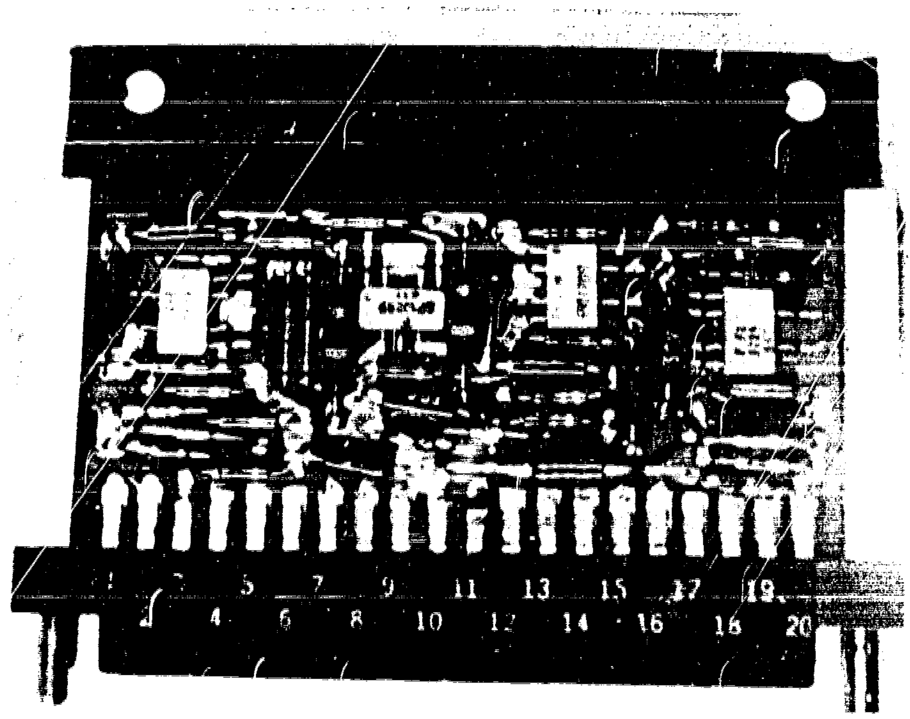

Figure 18. Basic Module with Mixed Components

A highly compact module is shown with integrated circuits, resistors, and capacitors. Pin number 11 is always ground. The guide pins are slotted and oriented differently among module types to prevent accidental plug-in.

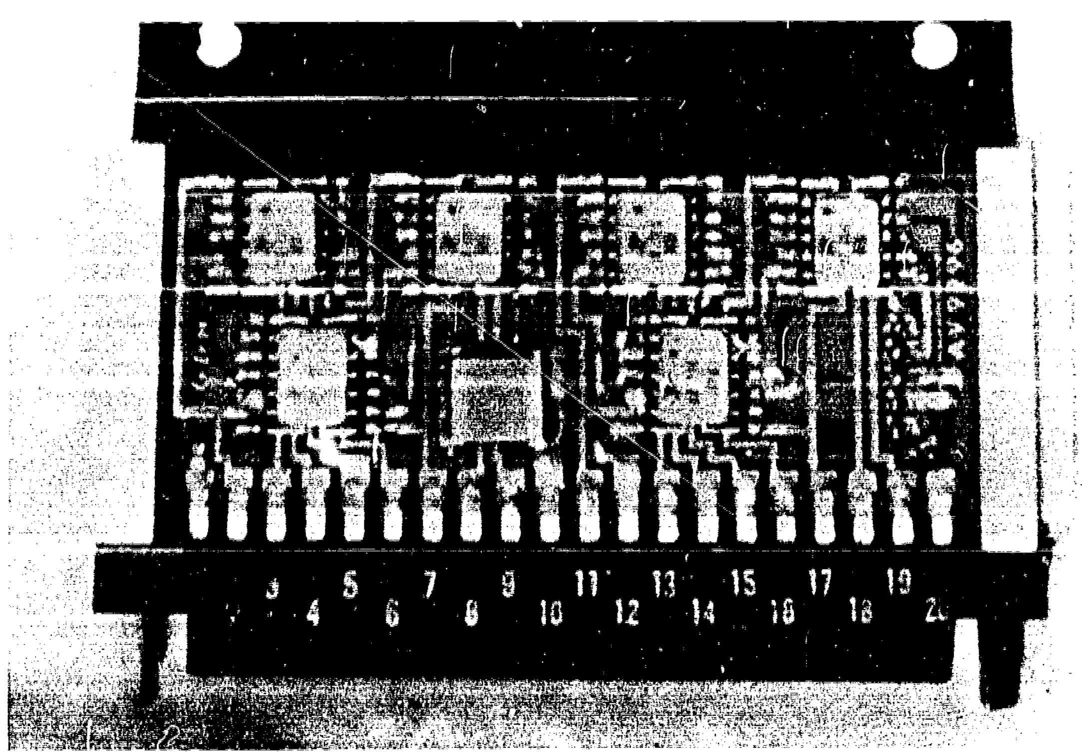

Figure 19. Basic Module Totally Implemented with Integrated Circuits

Components can be mounted on both sides of the cooling fin. Two sets of plug-in connectors are provided for a total of 40.

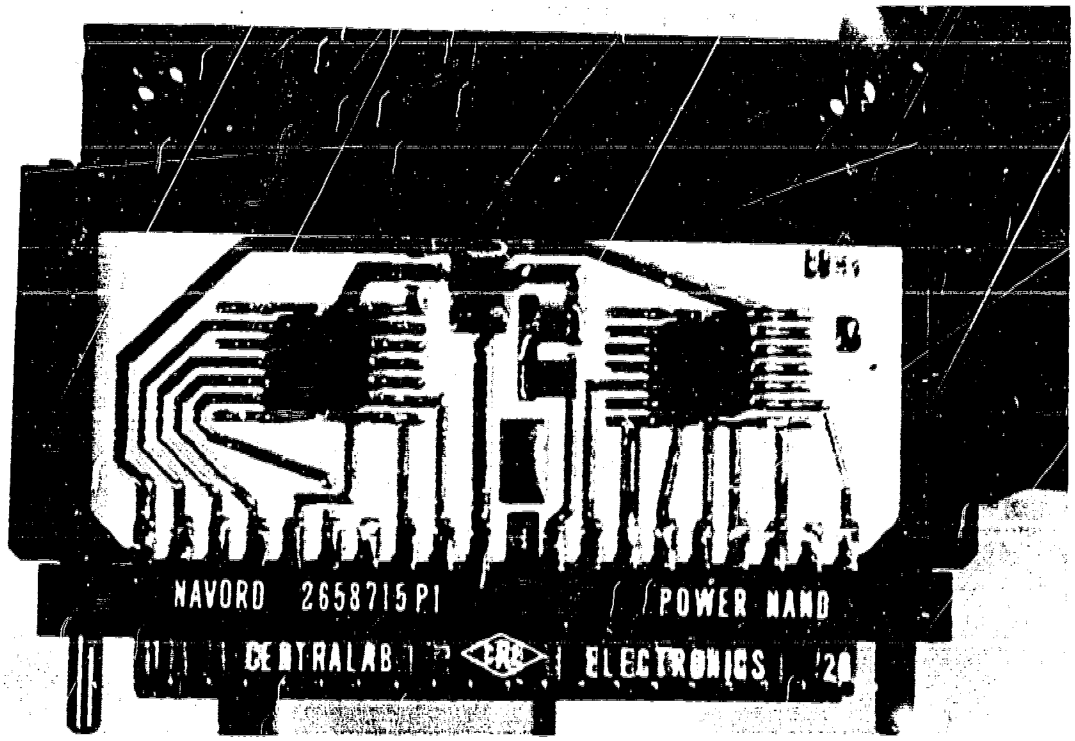

Figure 20. Basic Module with MSI

Two, medium-scale, integrated circuit chips are mounted with associated components. A plastic pin protector has been used; the pins can be clearly seen. There are more than 20 qualified suppliers of SHP modules.

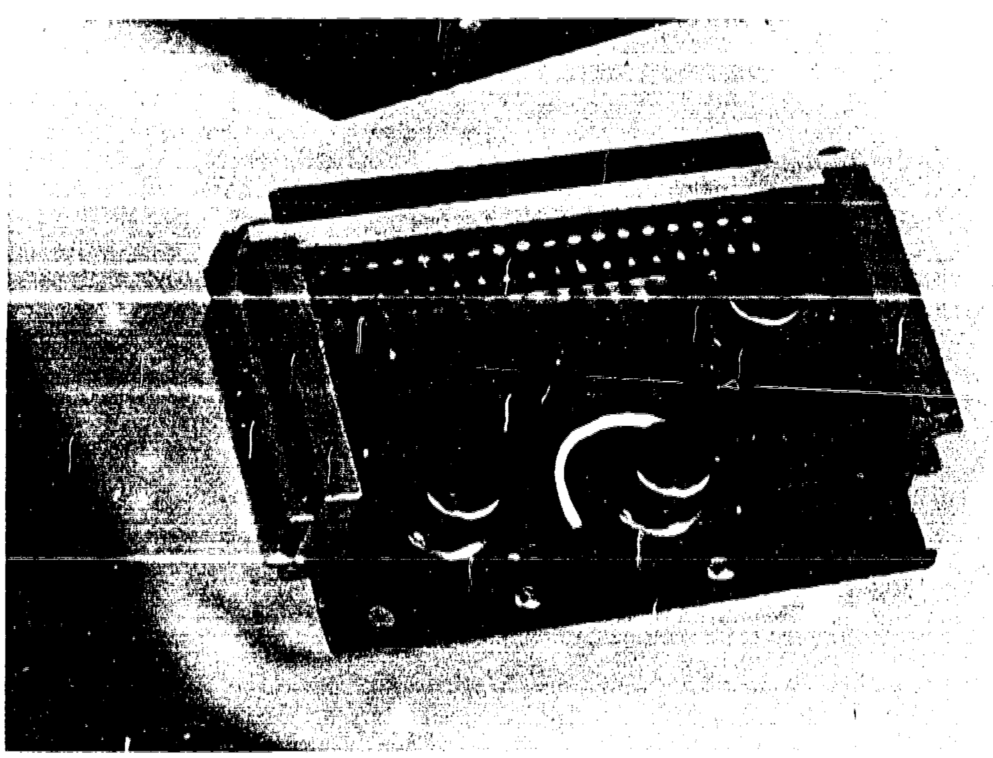

Figure 21. Double-Thickness Module with Power Transistors

Provision has been made for the basic module to expand in thickness. Power-handling components can be accommodated; proper cooling must be provided.

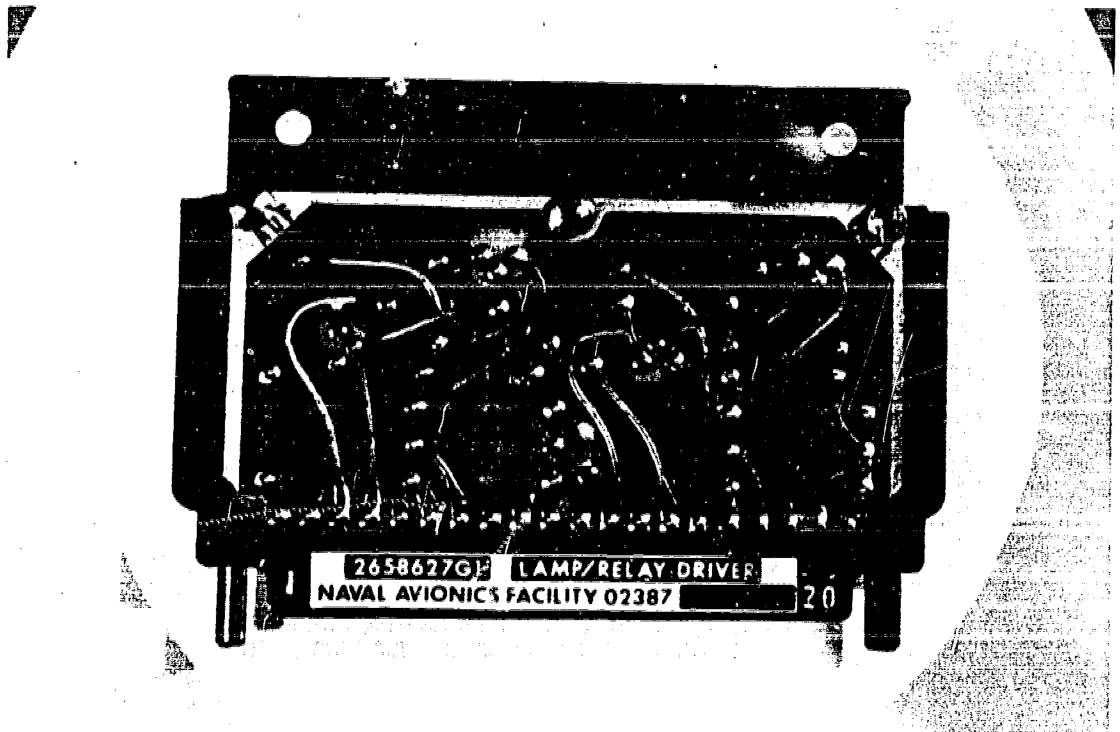

Figure 22. Basic Module with Picture Frame Construction

A newer form of the basic module using internally-mounted components and a printed circuit board fastened to the cooling fin frame.

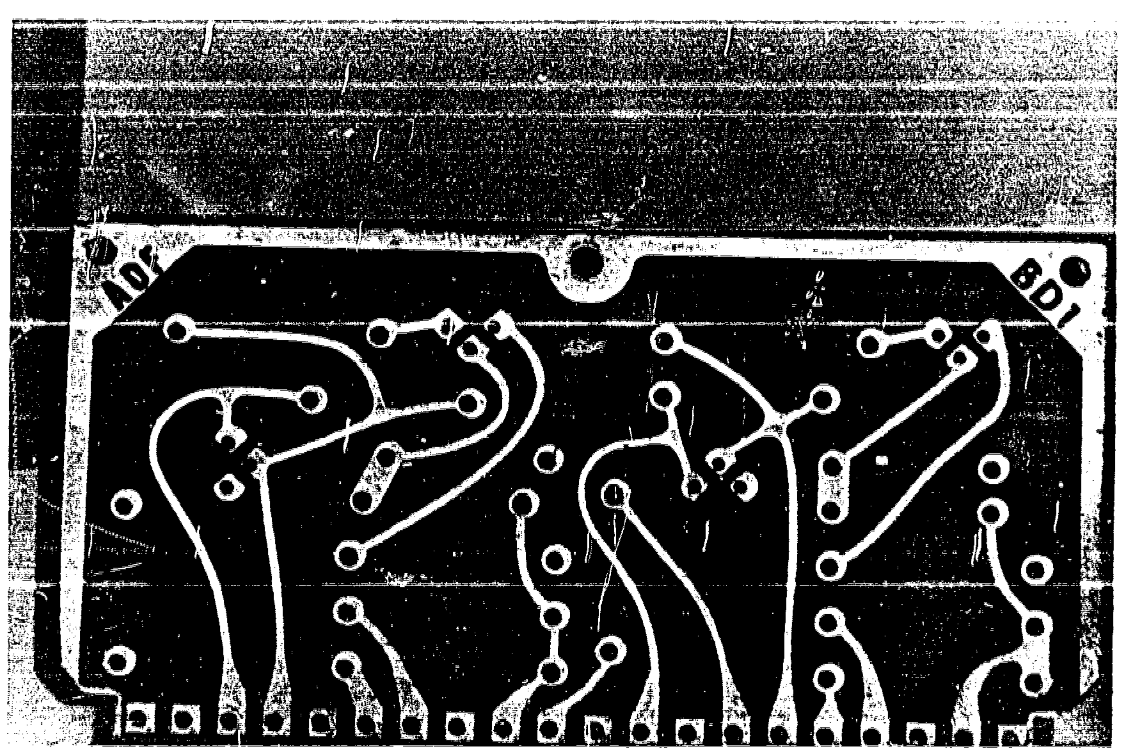

Figure 23. Printed Circuit Board

The printed circuit board is shown prior to mounting components and before being attached to the cooling fin. The printed circuit board is developed using an etching and depositing process.

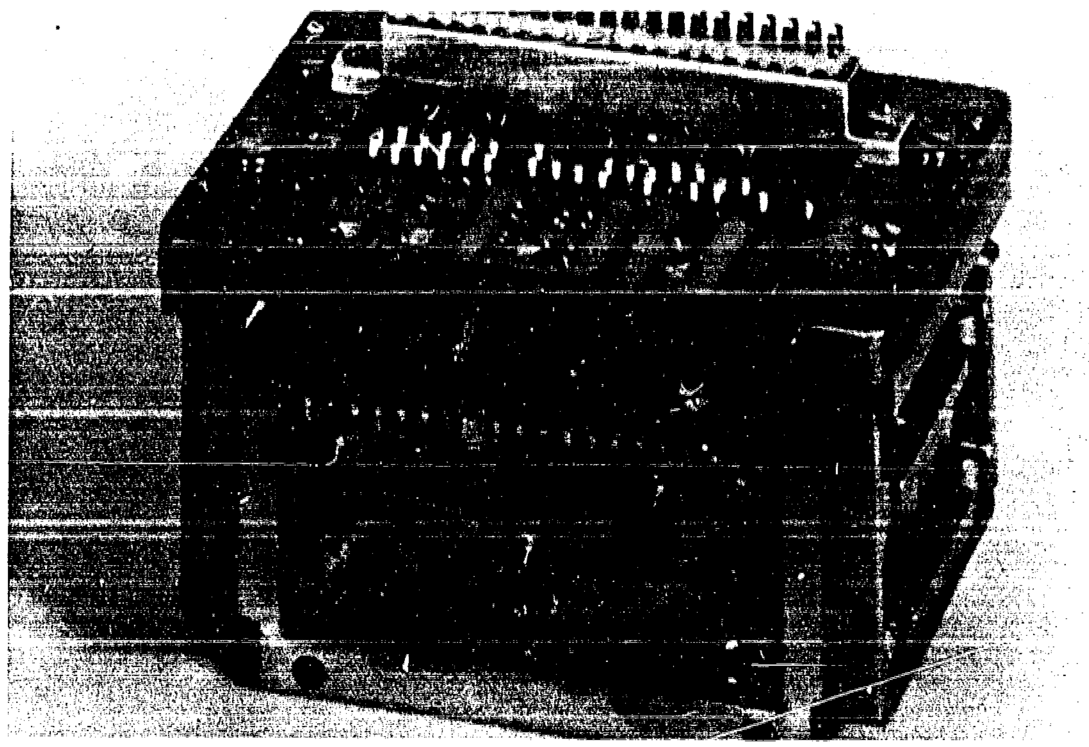

Figure 24. A Plug-In Power Supply

Several modules are combined in a card-cage to make a complete, plug-in unit. It becomes the smallest replaceable unit of hardware.

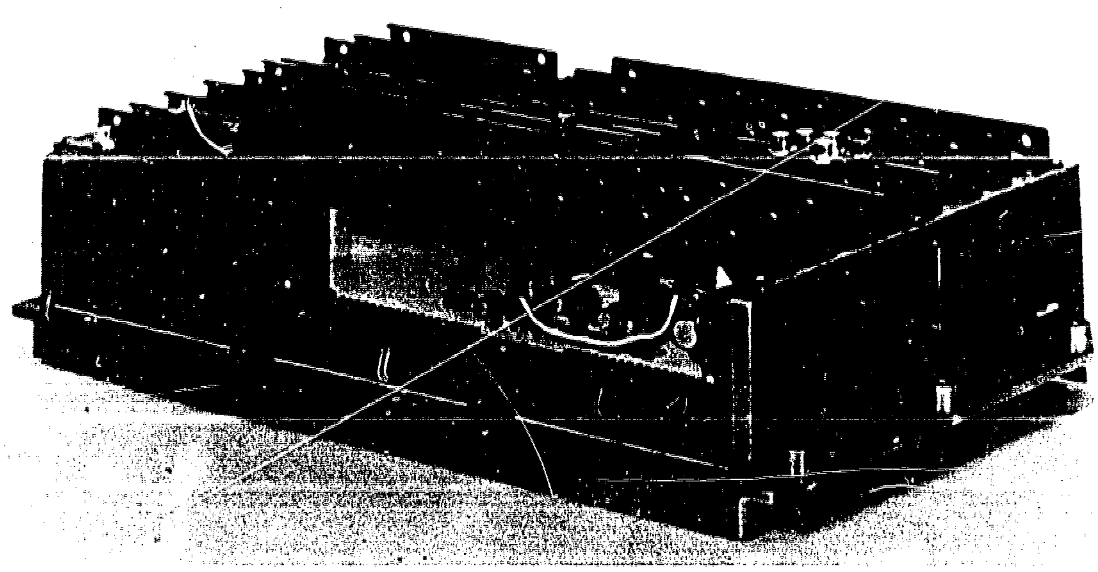

Figure 25. Double-Thickness and Double-Span Module

An airborne electronic device illustrating the growth of modules in both dimensions. BNC connectors can be seen at upper right on top of three modules, illustrating the use of SHP for radio-frequency applications.

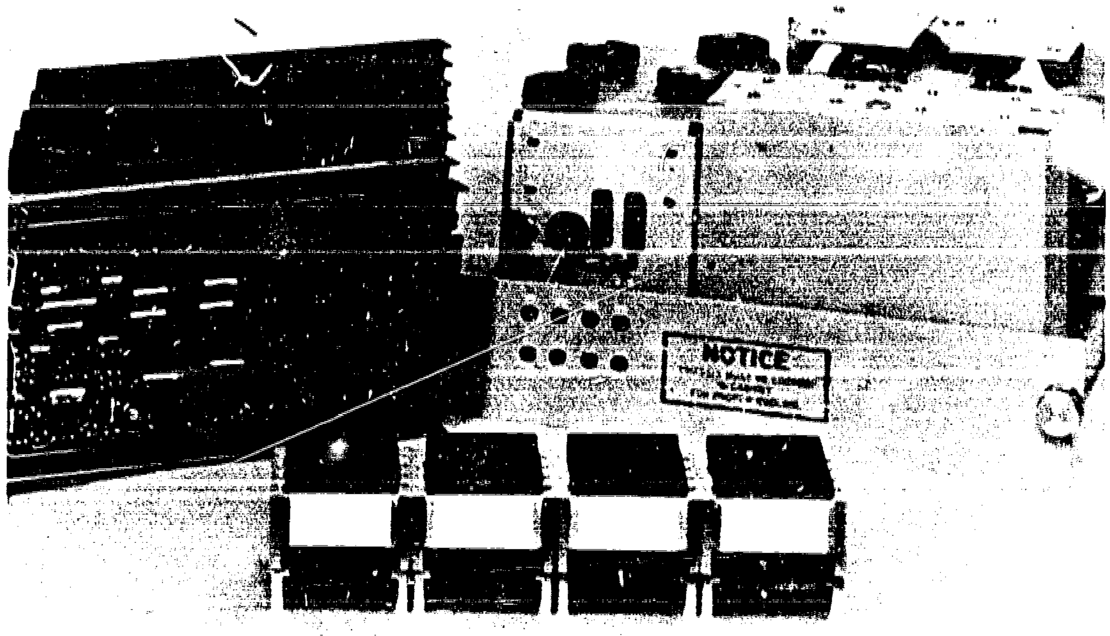

Figure 26. SHP Packaging Effectiveness

A contrast of two ways of packaging electronic hardware; conventional and SHP. At left are eight circuit boards with associated components. At lower center is the same circuitry packaged in SHP format, with associated card cages. At right is the completed equipment.

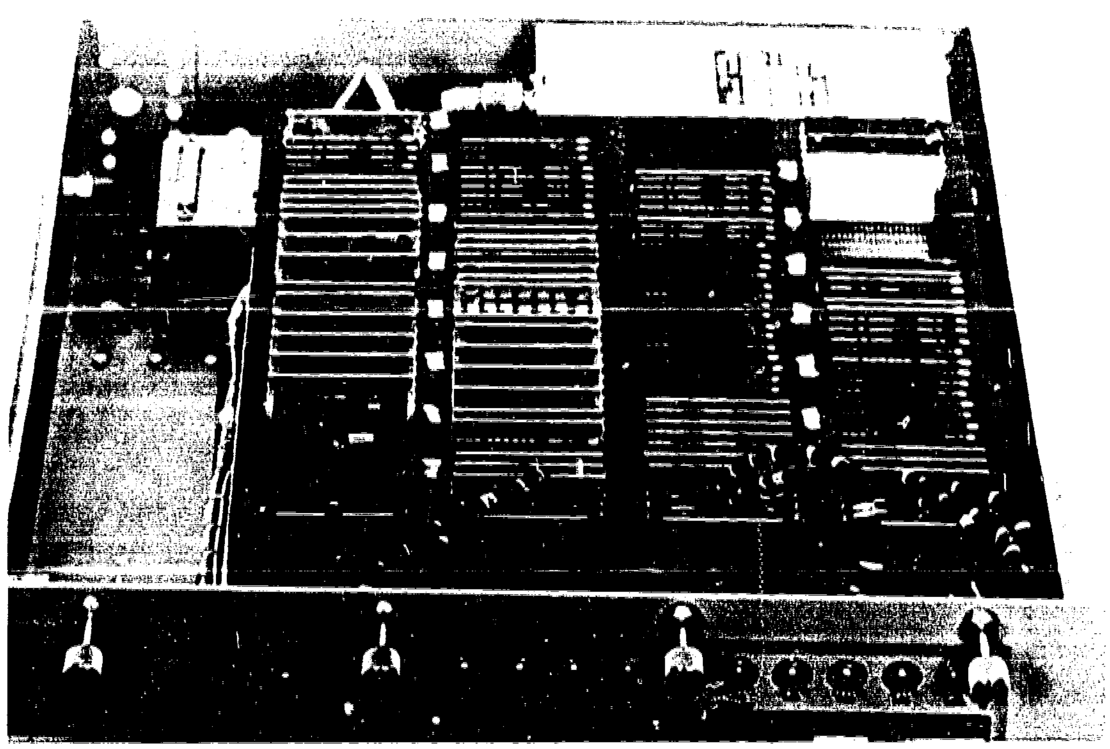

Figure 27. Pull-Out-Drawer Packaging

The drawer fits into a standard equipment rack. It can be pulled out for easy access to approximately 100 SHP modules. The identifying codes for each module type can be seen on top of each module cooling fin.

APPENDIX B

LIST OF PERSONS INTERVIEWED

Following is a list, in chronological order, of persons interviewed during the study. The organization represented and the purpose of the interview also are shown. The information and assistance provided by these people is gratefully acknowledged.

NAME	ORGANIZATION	PURPOSE
David Gold	Strategic Systems Project Office	Learn of Standard Hardware Program (SHP) involvement and standardization efforts in the FBM program.
Vince Ruddiman	Naval Training Device Center	Learn details of NTDC standardization program.
Dave Zimmerman	Naval Avionics Facility, Indianapolis	Learn details of SHP program.
Melvin Swager	Naval Avionics Facility, Indianapolis	Learn details of SHP hardware implementation and packaging.
Leo Welsh	Naval Avionics Facility, Indianapolis	Identify Naval programs using SHP techniques.
Harry Dickinson	Naval Material Command	Obtain details of standardization efforts in Naval Material Commands.
John Hammond	Naval Undersea Center, San Diego	Learn details of multi-mode display console.
Dean Hanna	Naval Undersea Center, San Diego	Learn detail operation of multi-mode display console.
Ernest Pool	Singer-Librascope	Discuss Mk 113, MOD 9 Fire-Control System.

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John Merz	Naval Electronic Systems Command	Learn the status and future direction of the SHP from the point of view of NAVELEX.
Frank Ingham	Naval Air Systems Command	Learn of the impact of recent developments in standardization of Naval equipment on procurement practices of NAVAIR.
John Cole	Naval Ship Systems Command	Learn the details of the application of standard hardware to NAVSHIPS programs and document the impact of standardization efforts on ship equipment.
Dick Kowaliw	Challenger Research, Inc.	Learn details of support effort to PM-1 and future direction and speed of standardization programs from Challenger's viewpoint.
Charles Green	General Motors Defense Research Laboratory	Learn details of GM's multi-mode console developments and view demonstration of equipment flexibility.
Clare Burgis	Singer-Librascope	Discuss design details of general-purpose display systems developments.
George Horn	Bureau of Naval Personnel	Document the training pipeline for the fire-control technician (Polaris) rating.
Bernard Monnes	Bureau of Naval Personnel	Document the training pipeline for the electronic technician rating.
Lt. Larry Krause	Bureau of Naval Personnel	Document the training pipeline for the data systems technician rating.
Joe Flynn	Bureau of Naval Personnel	Document the training pipeline for the sonar technician rating.
John Pinning	Bureau of Naval Personnel	Document the training pipeline for the torpedo maintenance technician rating.

William D. Wilson	Naval Ordnance Systems Command	Learn of expected maintenance techniques required by the Mk 116 Fire-Control System.
Cal Lawrence	Naval Ordnance Systems Command	Learn of maintenance techniques required by the Mk 113/9 and 113/10 Fire-Control Systems.
John Marlin	Naval Ship Systems Command	Obtain information on plans for the central computer complex aboard the Spruance class destroyer (DX).
Dr. Glenn Bryan	Office of Naval Research, Personnel and Training	Learn details of programs on computer-based instructional techniques for electronic maintenance.
Dr. Marshall Farr	Office of Naval Research, Personnel and Training	Learn names and addresses of persons conducting research in electronic performance assessment.
Clyde Ward	Naval Electronic Laboratory Center	Learn details of NELC's efforts in new packaging techniques for Naval hardware.
Dr. Joe Rigney	Electronic Personnel Research Group, University of Southern California	Learn details of the TASK-TEACH program of computer-based maintenance instruction.
G. L. Cumpston	Naval Electronic Systems Command 056	Obtain information on communication systems procurements.
Lt. R. O. Chancellor	Naval Electronic Systems Command 056	Obtain information on communication training devices.
George Koenig	Naval Electronic Systems Command 04T	Obtain information on present procurements being made by NAVELEX.
Harold Falcon	Naval Electronic Systems Command 04T	Outline procurement responsibility of NAVELEX.

D. C. Bailey	Naval Electronic Systems Command 03	Obtain information on digital communication systems.
Cdr. W. R. Beck	Naval Electronic Systems Command 046	Obtain information on maintenance philosophies for NAVELEX equipment.
Frank Guinti	Army Signal Schools Command	Familiarization with Army CAI project for electronic maintenance training.
Albert Mizenko	Army Signal Schools Command	Obtain information on Army plans for computerizing instruction in electronics.
Charles Anderson	Army Signal Corps, Educational Specialist	Become familiar with the objectives of Project COBET for electronic training.
LtCdr. M. M. Casebeer	Naval Schools Command, Treasure Island	Learn organization of ET(R) and ET(N) training schools.
ETCM Warburton	Naval Schools Command, Treasure Island	Obtain detailed information on electronic technicians school curricula.
Edward Cushing	Naval Schools Command, Educational Specialist	Learn of future plans for automated instruction.
LtCdr. K. Newton	Electronic Warfare School, Treasure Island	Examine curricula and obtain information on EW maintenance training.
Lt. Teal	Naval Schools Command, Treasure Island	Obtain information on present training device utilization at TI.
Capt. J. M. Campbell	Naval Schools Command, Mare Island	General discussions of future directions in Naval electronics maintenance training.
LtCdr. Sanborn	Naval Schools Command, Mare Island	Overview of training pipeline for data systems technicians.
DSCM Crompton	Data Systems Technician School, Mare Island	Review requirements for digital training devices in A_1 course.

D. S. Jordan	Data Systems Technician School, Mare Island	Review requirements for training devices in course A_2.
W. O. Brown	Data Systems Technician School, Mare Island	Review requirements for training devices in Class C maintenance training course.
Dr. Al Abrams	Naval Personnel Research & Training Lab, San Diego	Discussions on ET personnel and training.
LCDR Roger Harper Mr. H. C. McDowell	Naval Personnel Research & Training Lab, San Diego	Discuss occupational analyses for ET rates.
Mr. J. J. Bershtein Dr. Gaylord	Naval Personnel Research & Development Lab, Washington, D. C.	Discuss program to examine ET rates for new rating structures in 1975-1980.
LT J. E. Ritter	FBM Training Staff USN Service School, Dam Neck	Examine curricula and obtain information on ET "A" School training.
LCDR E. R. Van Hoof CDR R. W. Miller	FBM Training Staff USN Service School, Dam Neck	Discuss subject-area commonalities in Polaris/ Poseidon maintenance training.
LCDR Johnston	FBM Training Staff USN Service School, Dam Neck	Discuss problems related to digital equipment in navigation systems.
FTCM G. Addleman	FBM Training Staff USN Service School, Dam Neck	Discuss problems in digital logic training.
LCDR C. R. Cassaday	ET Schools, USN Service Schools, Great Lakes	Discussion on ET Schools' organization and objectives.
LT G. B. Swearinger	ET Schools, USN Service Schools, Great Lakes	Obtain information on curricula for A2.
Mr. L. A. Gelyer	ET Schools, USN Service Schools, Great Lakes	Obtain information on A3(R) and A4(R) curricula.

Mr. J. Colombo	ET Schools, USN Service Schools, Great Lakes	Obtain information on curricula evaluation.
LT W. Marguson	FT Schools, USN Service Schools, Great Lakes	Obtain information on FT training and curricula.
LT R. H. Oliver	BE&E Schools, USN Service Schools, Great Lakes	Obtain information on BE&E curricula and instructional techniques.
Mr. W. Guthrie	Naval Training Device Center, Orlando	Discuss status of torpedo maintenance trainer.

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13. ABSTRACT The purpose of this study program was to identify applications and develop design characteristics for generalized training devices. A secondary, but important, objective of the study was to forecast the impact on generalized training devices of new developments and design trends for Naval electronic equipment, maintenance procedures, and new training techniques. *** The first phase of the study was a detailed review of new developments in Naval equipment technology that influence the design of maintenance training devices--solid-state circuitry, modularization, digital technology, standardization, functional packaging, general-purpose displays, computer aiding, automatic test equipment, lifetime spares design, life-cycle costing, and total system design. These developments are reviewed and a series of long-term design trends is described. *** The second phase of the study had two general objectives: (1) to examine present training practices in electronics maintenance for a series of selected Naval rates, and (2) to identify skill and knowledge requirements created by Naval systems now in the conceptual and engineering design stages of their development cycles. As a result, three generalized training devices were recommended for development: (1) a digital systems training device, (2) a communications system training device, and (3) a generalized torpedo maintenance training device. *** The objective of the third phase of the study was to develop the design and use characteristics of the three recommended training devices with particular emphasis on the digital systems trainer. Each of the three devices is developed to the functional block diagram level and its role in Naval training is described, including the school(s) for which it was intended. *** Finally, recommendations are made for the inclusion of computer-assisted-instruction techniques as they relate to the digital systems trainer.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Generalized maintenance training						
Electronic maintenance training						
Digital Systems Trainer						
Communications Systems Maintenance Trainer						
Training Device						
Torpedo Maintenance Trainer						